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SPATIAL DISTRIBUTION AND DENSITY OF CETACEANS IN THE EASTERN TROPICAL PACIFIC OCEAN BASED ON SUMMER/FALL RESEARCH VESSEL SURVEYS IN 1986 - 96

by

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SPATIAL DISTRIBUTION AND DENSITY OF CETACEANS IN THE EASTERN PACIFIC OCEAN BASED ON SUMMER/FALL RESEARCH VESSEL SURVEYS IN 1986-96

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Abstract

We estimated meso-scale density and abundance of cetaceans in the eastern Pacific Ocean during the summer and fall seasons. The study area encompasses over 25 million km², ranging from the tip of the Olympic Peninsula to the north, the coast of Peru to the south, and the Hawaiian archipelago to the west. Cetacean sighting data were obtained from nine research vessel surveys conducted between 1986 and 1996. We used line-transect methods to analyze the data, relying on published estimates of the line-transect parameters $f(0)$ and $g(0)$. When data were adequate, we stratified geographically by 5-degree squares of latitude and longitude. Our results illustrate clear patterns in cetacean distribution and abundance that differed for virtually every species.

I. Introduction

Oceanic ecosystems are heterogeneous and dynamic. Physical and biological pattern and diversity in the ocean are evident across a continuum of spatial and temporal scales, and examining marine systems on the appropriate scales is crucial for understanding how they function. Haury *et al.* (1978) wrote:

"It is evident that organisms have aggregated, patchy distributions of abundance on a wide variety of space and time scales....Further,...patchiness strongly affects our efforts to obtain estimates of the abundance of organisms and our ability to detect significant spatial and temporal changes in abundance. It is therefore of great importance that we understand its nature, causes, and effects."

These heterogeneous and variable characteristics are reflected in the patterns of cetacean (whale, dolphin, and porpoise) abundance and distribution. We would like to be able to predict the structure (distribution and abundance) of cetacean populations in the wild. This requires: 1.) determining which biotic and abiotic variables are important in structuring cetacean populations, 2.) determining how populations respond to changes in these variables, and 3.) characterizing the spatial and temporal variation in those variables across relevant scales. Because it is difficult, if not impossible, to conduct controlled experiments on cetacean populations in the wild, the first task, and that with which this study is concerned, is to examine patterns in cetacean distribution and abundance. The second task, which we plan to address in a future investigation, is to look for correlations between population structure and environmental variables.

Ecologists have found species-environment correlations in many different groups of marine animals, including zooplankton (Fager and McGowan 1963), epipelagic nekton (*i.e.*, fishes and squids; Pearcy *et al.* 1996), and cetaceans (Reilly and Fiedler 1994, Fiedler and Reilly 1994, Forney 1997, and

Reilly *et al.*, 1997). Reilly *et al.* (1997) investigated habitat use patterns by cetaceans in the California Current during a summer-fall cruise in 1991 and determined that "the strongest patterns occurred in relation to spatially-structured oceanography." They argued that, for most cetacean species, oceanographic processes were important because they determined prey distribution and availability. Forney's (1997) work indicated that the species-environment patterns of cetaceans off California were consistent in 1991, 1993, and 1996. Nevertheless, although cetacean habitat use patterns appear constant in annual snapshots, seasonal variation is evident in the distribution (Reilly 1990) and abundance (Forney 1997) of some cetacean species, and interannual variation in abundance estimates also has been observed (Fiedler and Reilly 1994). Fiedler and Reilly attributed at least some of the interannual changes in abundance estimates of spotted (*Stenella attenuata*) and eastern spinner (*S. longirostris orientalis*) dolphins in the eastern tropical Pacific to "expansion of high quality habitat beyond the geographic ranges assumed for the abundance estimate." Further insight concerning which variables are related to cetacean distribution and abundance may be gained by studying a broader range of habitats and identifying the smaller blocks of space and time into which the overall structure may be decomposed.

In this study we examine the distribution and abundance of cetaceans in a large part of the eastern Pacific Ocean. Data were collected on nine marine mammal survey cruises conducted between 1986 and 1996 by the National Marine Fisheries Service Southwest Fisheries Science Center (NMFS/SWFSC), a division of the National Oceanic and Atmospheric Administration (NOAA). Cetacean abundance estimates from the 1986-1996 cruises have been published previously (Barlow 1988, Wade and Gerrodette 1993, Gerrodette 1993, Barlow and Gerrodette 1996, Gerrodette and Palacios 1996, Barlow 1997, and Koski *et al.* 1998).

Koski *et al.*'s (1998) analysis of the estimated density and abundance of marine mammals in the Navy planning areas at the Point Mugu Sea Range off California is the most similar to our study with respect to spatial resolution. The area of the geographic strata in Koski *et al.*'s study ranged from approximately 3400 km² to 209,000 km². We divided our study area into strata ranging from approximately 68,400 km² to 3,090,000 km². Koski *et al.* used line-transect methods to analyze data collected during marine mammal surveys, including NMFS/SWFSC ship and aerial surveys conducted between 1991 and 1994, and Bureau of Land Management Minerals Management Service (BLM/MMS) aerial surveys from 1975 to 1978 and 1980 to 1983. Incorporating the older BLM/MMS aerial surveys into their analysis allowed Koski *et al.* to incorporate seasonal variation in marine mammal abundance and distribution, although this also potentially introduced bias. The seasonal distributions of marine mammal species in the study area might have changed since the BLM/MMS surveys were conducted. Furthermore, data from surveys conducted using different methods are not entirely compatible because sighting probabilities may vary with the observation platform used. If the differences in sighting probabilities are not accounted for in the data analysis, the density or abundance estimates produced may be biased. Therefore, Koski *et al.* used weighting factors to try to account for potential biases resulting from incorporation of both aerial and ship-based survey data in their analysis.

Our investigation considers a broader oceanographic and geographic range than did any of the previous analyses of the NMFS/SWFSC research vessel survey data. It is intended to be used only as a quantitative tool to describe historical cetacean distribution and abundance, and not as a predictive model. The results presented here will be incorporated into the geographic information system LMRIS (Living Marine Resources Information System), which is being developed to provide the U.S. Navy with information regarding the distribution and abundance of marine mammal and turtle "species of concern." Further analyses are necessary for interpreting the observed habitat use patterns in light of physical, biological, and historical variables in order to create a predictive model of cetacean distribution and abundance.

II. Methods

Data for this analysis were collected by visual observers during nine NMFS cruises over a period of eleven years: five annual Monitoring of Porpoise Stocks (MOPS) cruises from 1986 to 1990; the California Marine Mammal Survey (CAMMS) of 1991; two Population of *Delphinus* Stocks (PODS) cruises, in 1992 and 1993; and the Oregon, California and Washington Line-transect Experiment (ORCAWALE) of 1996. All surveys were conducted between late July and early December of each survey year.

A. Study Area

The geographic extent of the combined survey area is vast, including over 25 million km² of the eastern Pacific Ocean. It stretches from the tip of the Olympic Peninsula in Washington at 49°N to the coastal waters of Peru at 13°S, and from the west coast of the Americas to the Hawaiian archipelago at 155°W (Figure 1). Survey effort off the western coast of the United States was limited to the waters within 300 nmi of the continent. The study area covers a wide range of oceanographic diversity. For example, oligotrophic waters in the subtropical gyres have relatively low productivity, whereas the California and Peru/Chile Currents, and the equatorial circulation system are highly productive

B. Field Methods

Survey methods remained relatively consistent throughout this 11-year study period. Two NOAA ships were used in most years: the 52 m David Starr Jordan and the 53 m McArthur. On both ships, the observation height from the flying bridge deck was approximately 10 m above the sea surface. The primary team consisted of two observers (port and starboard) who searched through 25x150 Fujinon pedestal-mounted binoculars (typically from 10° on the opposite side of the bow to 90° abeam on their respective sides) and one center observer who searched by unaided eyes and (occasionally) with 7x50 hand-held binoculars. The center observer also was responsible for recording search effort and sighting data. Observers rotated among these three observation stations for two hours and then had two hours off-duty. The vessels surveyed pre-determined transect lines at approximately 10 kts during daylight hours

(dawn to dusk). Typically when a marine mammal was sighted, the observer team went off-effort and directed the ship towards the animal(s) to obtain species identity and group size estimates. Immediately after making a sighting (and before turning the ship), the bearing angle from the bow to the animal (or the approximate center of a group of animals) was measured using a protractor at the base of the 25x binoculars, and the distance to the animal (or group) was estimated from measurements based on ocular reticles (Lerczak and Hobbs 1998).

Periods of search effort were carefully documented. Conditions that affected search were recorded at the start of effort and whenever conditions changed; these included Beaufort sea state, presence of rain or fog, and (starting in 1991) swell height and air clarity (estimated visibility in nautical miles to a conspicuous cue).

Sightings were classified to the lowest taxonomic level(s) possible based on observable field characteristics (*i.e.*, size, shape, blow, behavior, color). For *Stenella attenuata* and *Stenella longirostris*, sightings were often classified into subspecies or stocks. Some sightings could not be identified to species, in which case the sighting was assigned the lowest taxonomic category for which identification was certain (*e.g.*, *Kogia* species, or unidentified rorqual). Because a large fraction of *Kogia* and *Mesoplodon* sightings were identified only to genus, we limited our analyses to those two categories. For groups with multiple species, observers independently estimated the percentage of each species present; we averaged these percentages to estimate the number of each species present in a group. Overall group size also was estimated independently by each observer as "best," "high," and "low" estimates of the numbers present. Species percentages and group sizes were transcribed from individual field notes into the data record at the end of each day by the cruise leader; to maintain independence, observers were not allowed to compare their estimates with each other.

A few changes in protocol were implemented during this time period, but these are not expected to significantly affect the collection of the basic line-transect data. A conditionally independent observer position was used intermittently after 1991 to measure the fraction of animals missed by the primary team; however, the independent observer was instructed not to announce a sighting until the animal(s) had passed abeam and clearly had been missed by the primary observer team. Data from the independent observers were used to derive the correction factors that we use for estimating perception bias (Barlow 1995), but otherwise are not used in this report. In 1991, a computer-based data entry system replaced a system based on paper forms. In 1996, approximately one third of the effort was conducted in passing mode (*i.e.*, not turning towards or approaching cetaceans), and a new data field was recorded to indicate survey mode.

Surveys were designed to cover different geographic areas in each year. The cruises in 1986-90 were designed to estimate the abundance and trends in abundance for all dolphin populations that are affected by tuna fishing in the eastern tropical Pacific. The survey in 1991 was designed to estimate the abundance of all cetaceans in waters offshore of California. The surveys in 1992 and 1993 were designed to estimate the abundance of the central and northern stocks (respectively) of common dolphins (*Delphinus delphis*) in the eastern Pacific. The survey in 1996 was designed to estimate the abundance of all cetaceans

in waters offshore of California, Oregon, and Washington. Despite different goals, all sightings of cetaceans were consistently recorded on all cruises. Most groups sighted within 3 nmi of the transect lines were approached for species identification and group size estimation.

C. Analytical Methods

Data were analyzed using line-transect methods (Buckland *et al.* 1993). We estimated density (D_{aij}) in each geographic stratum as:

$$D_{aij} = \frac{n_{aij} S_{aij} f_{ik}(0)}{2 L_a g_{ik}(0)}$$

where

- j = species
- i = group size stratum (where applicable)
- a = geographic stratum
- n_a = number of sightings in geographic stratum a ,
- S_a = mean group size in geographic stratum a ,
- $f(0)$ = sighting probability density at zero perpendicular distance, or equivalently,
= 1/effective strip width,
- L_a = length of transect line completed in geographic stratum a ,
- $g(0)$ = probability of seeing a group located directly on the trackline, and
- k = species group to which species j belongs (where applicable).

For this analysis, a “species” refers to either a biological species or a management stock, depending on how the sightings were initially classified and recorded by visual observers in the field. We relied upon published estimates of the line-transect parameters $f(0)$ and $g(0)$ whenever possible (Table 1). In our estimates of species density and abundance in geographic strata for which estimates of $f(0)$ and $g(0)$ were not available, we substituted a published value estimated for another species with similar sighting characteristics and behavior in the same geographic location, or in a region of similar sighting conditions. In most cases, we used the truncation distance and range of Beaufort sea state conditions that were used in the original estimates of the line-transect parameters, as reported in the literature (Table 1). Exceptions are explained in the species descriptions that follow. We stratified by group size only those species and regions for which the published line-transect parameters were based on size-stratified data (Table 1). Where surveys overlapped spatially, all survey years were pooled and a single $f(0)$ value, calculated as described below, was used in the analysis.

Although previous analyses of these line-transect data have been relatively consistent in their methods, one notable difference exists. Visual observers in the field were asked to provide three estimates of school size for each sighting, namely a “low,” a “high,” and a “best” estimate. When multiple observers recorded group size estimates, the observers’ best estimates are typically averaged and used to compute mean school size. Sightings for which only a low estimate of school size was recorded were handled differently by Wade and Gerrodette (1993) and by Barlow and Gerrodette (1996) and Barlow (1997). To

calculate mean school size, Wade and Gerrodette (1993) excluded sightings for which only a low estimate was reported, but they included those sightings in n_{jk} and in their estimation of $f_{jk}(0)$. By contrast, if no best estimates were recorded for a given sighting, Barlow and Gerrodette (1996) and Barlow (1997) used an average of the low estimates to compute mean group size. This difference in methods tends to bias Barlow and Gerrodette's (1996) and Barlow's (1997) estimates of mean group size low compared with those of Wade and Gerrodette (1993). Because smaller schools are more likely to be "lost" and therefore be represented only by a low estimate, the true mean group size is likely to be somewhere in between those estimated as described above. We used Wade and Gerrodette's method of excluding sightings with only a low estimate for our analysis of the MOPS, PODS 92, and PODS 93 survey data collected south of 30°N. For the CAMMS 91, ORCAWALE 96, and PODS 93 survey data collected north of 30°N, we used Barlow and Gerrodette's (1996) and Barlow's (1997) method of averaging the low size estimates when best estimates were lacking. By dividing our analysis in this way, our estimates of mean group size should be comparable to those from previous publications.

Our method of dividing data for each species into geographic strata was based on the Beaufort criteria used in the original analyses. Considerably less survey effort was conducted during Beaufort 0-2 conditions (Figures 2 and 3) and, therefore, to increase sample size we used larger geographic strata for the analyses limited to calm seas than those in the Beaufort 0-5 analyses (Figures 4 and 5). For the latter, density estimates were calculated for individual 5° squares, excluding the area covered by land, when at least 700 km of transect line had been surveyed in each square. Squares located along the extreme margins of the study area and in which there was less than 100 km of survey effort were not included in the analysis. For all other squares with low survey effort, we pooled their data with that of neighboring squares to the east or west until the total length of transect line surveyed in the merged squares was at least 700 km. Using this criterion, the greatest number of merged 5° squares was three. We chose to pool Beaufort 0-5 squares in a latitudinal direction because we felt that this reflected the trends in the dominant oceanographic parameters at the relevant scales in the study area. Similarly, in the calm seas analysis, we merged squares so that the habitat within each geographic stratum was likely to be consistent. Thus, the 10° squares along the western U.S. and the 10°N strip reflect the California Current and the ITCZ, respectively. The rectangular strata in the southern waters of the study area are consistent with the characteristics of the equatorial currents and the Peru/Chile Current. The Gulf of California was divided into a northern component and a southern component for all analyses, regardless of Beaufort restrictions, because the survey and habitat conditions north of 30°N are generally considerably different from those to the south.

To facilitate data analysis, we divided the entire study area into four regions based on overlapping survey grids among the cruises and, presumably, similar sighting conditions and probabilities (Figure 6). The northernmost region (hereafter referred to as the "northern region"), is bordered by Washington and Oregon to the east, the 130°W meridian to the west, and the 45th and 50th parallels to the south and north, respectively. The northern region was surveyed only during the ORCAWALE cruise in

1996. The “middle region” is enclosed by the southern Oregon, California, and northern Baja coasts to the east, the 135°W and 130°W meridians to the west, and the 45th and 30th parallels to the north and south. The middle region contains areas surveyed during the ORCAWALE 96, PODS 93, and CAMMS 91 cruises. The third geographic block comprises the eastern tropical Pacific Ocean (ETP), extending from 30°N to 15°S, and 160°W to the coastline of Central and South America. It was surveyed during the annual MOPS cruises of 1986-1990, and the PODS cruises of 1992 and 1993. The fourth and smallest region encompasses the waters of the Gulf of California (“the Gulf”), which were surveyed only once, during the PODS 1993 cruise. For a given species, the same $f(0)$ and $g(0)$ values were used in all of the geographic strata contained within a given geographic region. The following discussion identifies the sources of those $f(0)$ and $g(0)$ values that we used in our analysis. The values and references are also listed in Table 1.

Balaenopteridae

***Balaenoptera acutorostrata*, Minke Whale**

The $g(0)$ that we used in all geographic regions was Barlow’s (1995) value for minke whales. The $f(0)$ for the northern region was Barlow’s (1997) value for small whales in the waters off California, Oregon, and Washington, which he calculated based on the ORCAWALE 96 cruise data. The $f(0)$ values that we used for the middle region are averages (weighted by total number of sightings of all species in the size stratum) of those for small whales as reported by Barlow and Gerrodette (1996) for California alone and by Barlow (1997). Neither Wade and Gerrodette (1993) nor Gerrodette and Palacios (1996) estimated $f(0)$ for minkes due to the small sample size, and therefore we used Barlow and Gerrodette’s (1996) $f(0)$ for small whales in our analyses of minke whales in the ETP and the Gulf regions.

***Balaenoptera edeni*, Bryde’s Whale**

The $g(0)$ values used for all surveys are those for large whales, estimated by Barlow (1995). The ETP data were not stratified by group size in this analysis. Therefore, we used only the $g(0)$ for small groups (1-3 individuals) of Bryde’s whales to analyze the ETP data because that is the range of typical group sizes for this species in the ETP. For sightings in the northern region, we used Barlow’s (1997) $f(0)$ for large whales. Densities from the middle region were estimated using a weighted average of the large whale $f(0)$ values from Barlow and Gerrodette (1996) and Barlow (1997), calculated as described above for minke whales. Wade and Gerrodette (1993) estimated an $f(0)$ for Bryde’s whales in the ETP, and we used their value for our analysis. Our analysis of Bryde’s in the Gulf was based on Gerrodette and Palacios’ (1996) $f(0)$ values.

***Balaenoptera borealis*, Sei Whale**

There was only one positive sighting of a sei whale in the survey area during all survey years, and it was located in the middle region. Therefore, we used Barlow’s (1995) large whale estimate for $g(0)$, and computed a weighted average of Barlow and Gerrodette’s (1996) and Barlow’s (1997) $f(0)$ values for large whales to estimate the density and abundance of this species.

We also calculated density and abundance estimates for the partially-identified category Bryde’s/sei whales, which was created due to the difficulty of distinguishing these species in the field.

Because of the lack of positive sei whale sightings, however, it is likely that the majority of sightings in this dual category were Bryde's whales. We analyzed the Bryde's/sei sightings using $f(0)$ and $g(0)$ values identical to those that we reported above for Bryde's whales.

***Balaenoptera physalus*, Fin Whale**

Barlow's (1995) large whale $g(0)$ value was used for analysis of fin whale data in geographic strata within all regions. For the fin whale analysis, like the Bryde's whale analysis, only the $g(0)$ for small groups of large whales was used to estimate densities in the ETP region. The $f(0)$ value in our analysis for the northern region came from Barlow (1997). For the middle region, we used the weighted average of $f(0)$ from Barlow and Gerrodette (1996) and Barlow (1997). Wade and Gerrodette (1993) did not compute an estimate of $f(0)$ for fin whales in the ETP due to the small sample size, so we used their $f(0)$ value for blue whales in our analysis. The $f(0)$ for fin whales in Gerrodette and Palacios (1996) was used to make a density estimate for the Gulf.

***Balaenoptera musculus*, Blue Whale**

Similar to our analysis of Bryde's, sei, and fin whales, we used Barlow's (1995) estimate of $g(0)$ to analyze all of the blue whale data. Like the fin and Bryde's whale analyses, our estimate of blue whale density and abundance in the ETP is based on a single $g(0)$ derived for small groups of large whales. The $f(0)$ for the northern region is from Barlow (1997). The $f(0)$ for the middle region is the weighted average for large whales from Barlow and Gerrodette (1996) and Barlow (1997). Wade and Gerrodette's (1993) $f(0)$ for blue whales was used for analysis of the ETP data. Blue whales were not sighted in the Gulf of California (Mangels and Gerrodette 1994).

***Megaptera novaeangliae*, Humpback Whale**

The sources of the $g(0)$ and $f(0)$ values that we used for humpback whales in all regions are identical to those that we used for fin and blue whales.

Unidentified Rorqual, Unidentified Large Whale, and Unidentified Whale

There are three "unidentified" taxonomic categories that complement our analyses of the Balaenopteridae family: unidentified rorqual, unidentified large whale, and unidentified whale. We used Barlow's (1995) large whale estimate of $g(0)$ for our analyses of all regions. Identical to our treatment of the Bryde's, fin, blue, and humpback whale data, we used Barlow's (1997) large whale $f(0)$ for the northern region, a weighted average from Barlow and Gerrodette (1996) and Barlow (1997) for the $f(0)$ of the middle region, and Gerrodette and Palacios' (1996) estimates of $f(0)$ for the Gulf. For the ETP, we calculated a weighted average of Wade and Gerrodette's (1993) $f(0)$ for blue whales and Bryde's whales.

Eschrichtiidae

***Eschrichtius robustus*, Gray Whale**

There were only two gray whale sightings in all of the surveys combined (Hill and Barlow 1992). Those sightings, however, were outside of the truncation distance or Beaufort sea state restrictions of the $f(0)$ values, and therefore this species was not included in our report.

Physeteridae

***Physeter macrocephalus*, Sperm Whale**

Barlow and Sexton (1996) calculated a separate $g(0)$ value for sperm whales, which we used for our analyses of all four geographic regions. The $f(0)$ values for the northern and middle regions were the same as those used for the Bryde's, fin, blue, and humpback whales listed above. For the ETP, we used Wade and Gerrodette's (1993) $f(0)$ value for sperm whales. For the Gulf, we used Gerrodette and Palacios' (1996) estimate of $f(0)$ for sperm whales.

***Kogia* species**

Two species, *Kogia breviceps*, the pygmy sperm whale, and *Kogia sima*, the dwarf sperm whale, share similar sighting characteristics. *K. breviceps* has a more northern distribution, whereas *K. sima* is typically found in the southern waters of our study area. Due to the difficulty in distinguishing these two species in the field, visual observation data include a category for "*Kogia* species". The data for sightings of *K. breviceps*, *K. sima*, and *Kogia* species were analyzed using identical $g(0)$ and $f(0)$ values. Barlow (1999) reported $g(0)$ values for long-diving whales, including one for *Kogia*, which we used in our analyses for all geographic regions. The "cryptic species" $f(0)$ from Barlow (1997) was used for *Kogia* sightings in the northern region. Similarly, a weighted average of the cryptic species $f(0)$ from Barlow and Gerrodette (1996) and Barlow (1997) was used for analysis of the middle region. Barlow and Gerrodette's (1996) value of $f(0)$ for cryptic species in calm (Beaufort 0-2) waters off California was used for the *Kogia* sightings in the ETP. Wade and Gerrodette (1993) also estimated $f(0)$ for *Kogia* in the ETP, although their estimate was for Beaufort 0-5 conditions, and we felt that limiting our analysis to calm water sightings would produce more accurate results. We used Barlow and Gerrodette's (1996) $f(0)$ for the analysis of the Gulf region because Gerrodette and Palacios (1996) did not estimate this parameter.

Ziphiidae

***Berardius bairdii*, Baird's Beaked Whale**

Berardius bairdii was included in Barlow's (1999) analysis of trackline detection probabilities for long-diving whales, and we used his $g(0)$ value for our analyses of all survey regions. The large whale $f(0)$ from Barlow (1997) was used for *B. bairdii* sightings in the northern region. Sightings made in the middle region were analyzed using a weighted average of the large whale $f(0)$ values reported in Barlow and Gerrodette (1996) and Barlow (1997). Baird's beaked whale was encountered too infrequently in the ETP for Wade and Gerrodette (1993) to calculate an $f(0)$ for this species, and therefore we used the $f(0)$ for large groups of large whales reported by Barlow and Gerrodette (1996) for our analysis of those waters. Baird's beaked whales were not encountered during the PODS 1993 survey in the Gulf.

***Indopacetus pacificus*(?), Tropical Bottlenose Whale**

Although sightings of this species were originally designated as *Hyperoodon planifrons* (Wade and Gerrodette 1993), Pitman *et al.* (1999) present compelling evidence that these cetaceans are really a new or imperfectly described tropical species of bottlenose whale. Tropical bottlenose whale sightings were limited to the ETP survey region. The $g(0)$ values for *Berardius bairdii* published in Barlow

(1999), and the $f(0)$ for large groups of large whales reported by Barlow and Gerrodette (1996) were used to estimate the density of tropical bottlenose whales.

***Ziphius cavirostris*, Cuvier's Beaked Whale**

We used Barlow's (1999) *Ziphius cavirostris* $g(0)$ value in the analyses of all regions. The $f(0)$ for the northern region is the value for small whales published in Barlow 1997. We used a weighted average of the small whale $f(0)$ values found in Barlow and Gerrodette (1996) and Barlow (1997) for our density estimate of Cuvier's beaked whales in the middle region. For the ETP data, we used Barlow and Gerrodette's (1996) published value of $f(0)$ for small whales in waters off California. The $f(0)$ for *Z. cavirostris* in the Gulf is Gerrodette and Palacios' (1996) value for the family Ziphiidae.

***Mesoplodon* species**

Visual observers identified three species of *Mesoplodon*, including *M. peruvianus*, *M. densirostris*, and *M. species "A."* The $g(0)$ and $f(0)$ values for these species, and for the general category of *Mesoplodon*, were identical for a given geographic region in our analysis. Barlow's (1999) $g(0)$ for *Mesoplodon* was used in analyses for all regions. The $f(0)$ for the northern region was Barlow's (1997) estimate for the small whale species group, and a weighted average of the small whale $f(0)$ values from Barlow and Gerrodette (1996) and Barlow (1997) was used for the middle region. The $f(0)$ for small whales off California which was published in Barlow and Gerrodette (1996) was used for the ETP region. Gerrodette and Palacios' (1996) Ziphiidae $f(0)$ value was used for the Gulf.

Ziphiid Whale

Visual observers assigned unidentified beaked whale sightings to the "ziphiid whale" category. The surveys in the northern region did not record any sightings in this category. For our analyses, we used a weighted average of Barlow's (1999) $g(0)$ values for *Ziphius cavirostris* and *Mesoplodon*. A separate weighted average of $g(0)$ was calculated for each region, with the total number of sightings recorded for each genus in each region used as weights in the calculation. Similar to the *Ziphius* and *Mesoplodon* species mentioned above, the weighted average of Barlow and Gerrodette's (1996) and Barlow's (1997) $f(0)$ values for small whales was used for analysis of the data from the middle region. Barlow and Gerrodette's (1996) $f(0)$ for small whales was used to estimate densities in the ETP. For the Gulf, we used Gerrodette and Palacios' (1996) Ziphiidae $f(0)$.

Unidentified Cetacean and Unidentified Small Whale

Unidentified cetacean and unidentified small whale sightings were analyzed together because the factors that impede the assignment of positive identification are similar in both cases and, therefore, the sighting probabilities are likely to be similar. We used estimates of $g(0)$ for small whales from Barlow (1995) to analyze the data from all regions. The $f(0)$ for the northern region analysis was Barlow's (1997) small whale $f(0)$. For the middle region, we used a weighted average of Barlow and Gerrodette's (1996) and Barlow's (1997) $f(0)$ for small whales. The analysis of the ETP data incorporated Barlow and Gerrodette's (1996) $f(0)$ for small whales, which was based only on sightings from waters off California.

Gerrodette and Palacios (1996) provided separate $f(0)$ values for these unidentified categories, which we used to produce density estimates for the Gulf.

Delphinidae

We calculated density estimates for each dolphin species separately based on the line-transect parameters outlined below, and then pooled the estimates within each geographic stratum to produce an estimate of total dolphin density per stratum.

***Stenella attenuata*, Spotted Dolphin**

Sightings of spotted dolphins were entirely contained within the ETP and the Gulf. We used Barlow's (1995) $g(0)$ value for small delphinids of group size 20+ to analyze all spotted dolphin sightings. For the Gulf, the $f(0)$ values are from Gerrodette and Palacios (1996). Our analysis of spotted dolphins in the ETP includes estimates of density for three stocks: the northeastern offshore stock, the western-southern offshore stock, and the coastal stock, which is designated as the subspecies *S. attenuata graffmani* (Dizon *et al.*, 1994). The coastal stock of spotted dolphins is defined to be located within 100 nmi of the Central and South American coastline, from the tip of the Baja Peninsula down to the westernmost tip of Peru, at approximately 6°S (Figure 7). The northeastern offshore stock is bounded by 120°W and 5°N, and it overlaps with the coastal stock within 100 nmi of the coast. The western-southern stock is found in waters west of 120°W and south of 5°N. Wade and Gerrodette (1993) provided values of $f(0)$ for the coastal, northeastern, and western-southern stocks separately. We divided the unidentified spotted dolphin sightings based on the stock boundaries defined above, and used the appropriate $f(0)$ values from Wade and Gerrodette to analyze the unidentified sightings within each stock boundary. For unidentified sightings located within 100 nmi of the coastline, we calculated a weighted average of the $f(0)$ value for the coastal stock and the northeastern or western-southern stock, depending on whether the sighting was north or south of 5° N. For unidentified spotted dolphins seen farther than 100 nmi offshore, the estimate of $f(0)$ for either the northeastern or western-southern stock was used.

***Stenella longirostris*, Spinner Dolphin**

All of the spinner dolphin sightings were from the ETP and the Gulf. We used Barlow's (1995) $g(0)$ for small dolphin schools numbering 20+ individuals to analyze all of the spinner dolphin data. For sightings located within the Gulf region, Gerrodette and Palacios' (1996) $f(0)$ values were used to estimate density. The boundaries of spinner dolphin stocks in the ETP are still rather uncertain. Visual observers classify spinner dolphin sightings as eastern spinners, whitebelly spinners, Central American or Costa Rican spinners (*S. longirostris centroamericana*), or unidentified spinners. Wade and Gerrodette's (1993) $f(0)$ values for eastern and whitebelly spinners were used where sightings were assigned to one of those stocks in the ETP. To analyze the *S. longirostris centroamericana* data, we used Wade and Gerrodette's $f(0)$ for eastern spinners because those two stocks overlap spatially. For unidentified spinner dolphin sightings, we calculated a weighted average of Wade and Gerrodette's eastern and whitebelly spinner $f(0)$ values.

***Delphinus* species, Common Dolphin**

The common dolphin sightings were divided among three categories, including one “unidentified common dolphin” category. *Delphinus capensis*, commonly known as the “Baja neritic” or “long-beak” common dolphin, was assigned to the second category of common dolphin. It is typically found within 100 nmi of the Pacific coast of Baja California and Peru, and in the Gulf of California (Figure 8; Heyning and Perrin, 1994), although our survey data indicate sightings off the central California coast, too. The third category of common dolphin in our analysis comprises *Delphinus delphis*, the “short-beak” common dolphin. Short-beak common dolphins are distributed throughout our survey region, and the northern stock of short-beak common dolphin overlaps with the long-beak common dolphin within 100 nmi of the coast. We did not distinguish between long-beak and short-beak common dolphins off Peru because our study area did not extend far into that portion of their range. For all common dolphin sightings in the northern region, we used size-stratified estimates of $g(0)$ and $f(0)$ for small delphinids from Barlow (1995) and Barlow (1997), respectively. For all common dolphin sightings in the middle region, we used Barlow’s (1995) size-stratified $g(0)$ values for small delphinids, and weighted averages of Barlow and Gerrodette’s (1996) and Barlow’s (1997) size-stratified values of $f(0)$ for small delphinids. Prior to the 1990 MOPS surveys, criteria had not been established to distinguish short-beak and long-beak common dolphins in the field. Therefore, for our analysis of the nearshore (<100 nmi) waters of the ETP region, we used data from only the 1990 MOPS survey and from both PODS surveys (1992 and 1993), thus restricting the analysis to the higher resolution data. To analyze sightings outside of the 100 nmi zone, we used the entire MOPS series (1986-1990) and data from both PODS years. In our analysis of common dolphin sighting data from the ETP, we used Barlow’s (1995) $g(0)$ estimate for small delphinid groups numbering in excess of 20 individuals. We did not stratify the ETP data by group size because dolphin groups in the ETP typically contain more than 20 individuals, and because the $f(0)$ values that we used for this region were not stratified by group size (Wade and Gerrodette 1993). Wade and Gerrodette reported three $f(0)$ values for the ETP, corresponding to the northern, central, and southern common dolphin stocks, all of which refer to the short-beak form (Figure 8). Because Wade and Gerrodette did not calculate a separate $f(0)$ value for the long-beak common dolphin, we used their northern common dolphin $f(0)$ for all sightings of *Delphinus* located within the northern stock boundaries. Similarly, Wade and Gerrodette’s central common and southern common dolphin estimates of $f(0)$ were used for all sightings within the central and southern stock boundaries, respectively. For the Gulf, we relied upon Gerrodette and Palacios’ (1996) estimates of $f(0)$ for *Delphinus delphis* and *Delphinus capensis* when common dolphin sightings were identified to species, and used a weighted average of the two for unidentified common dolphin sightings. Barlow’s (1995) estimate of $g(0)$ for schools of small dolphins containing more than 20 individuals was used to analyze all common dolphin sightings in the Gulf.

***Stenella coeruleoalba*, Striped Dolphin**

Stenella coeruleoalba were sighted in all regions except the Gulf. Striped dolphins were stratified by group size in analyses for the northern and middle regions. Barlow’s (1995) estimates of $g(0)$

for small delphinids were used for all geographic regions, although only the $g(0)$ for groups larger than 20 individuals was used in the analysis of the ETP sightings. The $f(0)$ values for the northern region came from Barlow (1997). Weighted averages of $f(0)$ estimates from Gerrodette and Barlow (1996) and Barlow (1997) were used in density and abundance estimates for the middle region. For the ETP, we used the $f(0)$ value of Wade and Gerrodette (1993). Gerrodette and Palacios (1996) provided an $f(0)$ value that we used for analysis of the Gulf data.

***Steno bredanensis*, Rough-toothed Dolphin**

The rough-toothed dolphin was sighted only in the ETP and the Gulf. We did not stratify our analyses of the *Steno* data by group size. For both regions, we used Barlow's (1995) $g(0)$ estimated for groups of large delphinids with more than 20 individuals. Wade and Gerrodette (1993) provided an estimate of $f(0)$ for rough-toothed dolphins in the ETP, and we used Gerrodette and Palacios' (1996) $f(0)$ value for our analysis of the Gulf.

***Tursiops truncatus*, Bottlenose Dolphin**

The range of bottlenose dolphins extends throughout the three southernmost regions in the survey area; no *Tursiops* were observed in the northern region. Barlow's (1995) $g(0)$ values for large delphinids were used, although only the middle region was stratified by group size for the analysis. All sightings from the ETP and the Gulf were analyzed using the $g(0)$ for groups of more than 20 individuals. The $f(0)$ for the middle region was calculated as a weighted average of the large delphinid $f(0)$'s from Barlow and Gerrodette (1996) and Barlow (1997). We used Wade and Gerrodette's (1993) $f(0)$ to analyze sightings in the ETP, and Gerrodette and Palacios' (1996) value to analyze data from the Gulf.

***Grampus griseus*, Risso's Dolphin**

Risso's dolphin is similar to the common dolphin in that it was found in all four survey regions. We stratified the Risso's dolphin analysis by group size for the northern and middle regions, but we did not stratify data from the ETP and the Gulf by group size, consistent with our treatment of the data for common, striped, and bottlenose dolphins. Barlow's (1995) large delphinid $g(0)$ values were used for all analyses, but only the value for group sizes exceeding 20 individuals was used for the ETP and the Gulf. The $f(0)$ values for the northern region were first reported in Barlow (1997), and those for the middle region are weighted averages of the large delphinid $f(0)$ values from Barlow and Gerrodette (1996) and Barlow (1997). Wade and Gerrodette (1993) and Gerrodette and Palacios (1996) published estimates of $f(0)$ for *Grampus* that we used in the analyses for the ETP and the Gulf, respectively.

***Lagenorhynchus obliquidens*, Pacific White-sided Dolphin**

The Pacific white-sided dolphin was sighted in all regions except the Gulf. *L. obliquidens* analyses were stratified by group size for all regions because the total number of sightings was small, and some of those were of small groups of dolphins. The $g(0)$ values were Barlow's (1995) for small delphinids. The northern region was analyzed using $f(0)$ values for small delphinids from Barlow (1997), and weighted averages of the corresponding $f(0)$ values from Barlow and Gerrodette (1996) and Barlow (1997) were used for the middle region. Few sightings of Pacific white-sided dolphins were made in the

ETP region, so Wade and Gerrodette (1993) did not calculate an $f(0)$ for this species. Therefore, we used Barlow and Gerrodette's (1996) estimate of $f(0)$, which was based on sightings only from the waters off California, to analyze the ETP data.

***Lagenodelphis hosei*, Fraser's Dolphin**

All Fraser's dolphin sightings were from the ETP. To estimate density and abundance of Fraser's dolphins, we used Barlow's (1995) $g(0)$ for large (20+ individuals) groups of small dolphins, and Wade and Gerrodette's (1993) $f(0)$ for this species.

***Lissodelphis borealis*, Northern Right Whale Dolphin**

No sightings of the northern right whale dolphin were made during survey cruises in the eastern tropical Pacific Ocean and the Gulf of California. To analyze the data from the northern and middle regions, we stratified *L. borealis* sightings by group size, and used Barlow's (1995) $g(0)$ values for small delphinids. The $f(0)$ values for the northern region are from Barlow (1997) and those for the middle region are weighted averages of the small delphinid $f(0)$ values from Barlow and Gerrodette (1996) and Barlow (1997).

***Peponocephala electra*, Melon-headed Whale**

Melon-headed whale sightings were restricted to waters of the eastern tropical Pacific. Barlow's (1995) $g(0)$ for large groups of large delphinids, and Wade and Gerrodette's (1993) $f(0)$ for *P. electra* were used in estimates of this species.

***Feresa attenuata*, Pygmy Killer Whale**

Pygmy killer whales were sighted only in the ETP. To estimate the density of this species, we used Barlow's (1995) $g(0)$ for large groups of large delphinids, and Wade and Gerrodette's (1993) *Feresa attenuata* $f(0)$.

***Pseudorca crassidens*, False Killer Whale**

Like the pygmy killer whale, all of the false killer whale sightings were from the ETP, and we analyzed the data for both species in a similar manner. We used Barlow's (1995) $g(0)$ for groups of large delphinids numbering more than 20 individuals, and the $f(0)$ that Wade and Gerrodette (1993) calculated for *Pseudorca crassidens* in the ETP.

***Orcinus orca*, Killer Whale**

The range of the killer whale extends throughout the four survey regions included in this analysis. We stratified the killer whale data by group size to analyze the data from the northern and middle regions, but did not stratify by group size in our analyses of the ETP and the Gulf, thereby keeping with our previous treatment of sighting data for dolphins with broad latitudinal ranges. Barlow's (1995) $g(0)$ estimates for large delphinids were used for all survey regions, although only the value for large groups of individuals was used for the ETP and the Gulf. The $f(0)$ values for the northern region are from Barlow (1997). Weighted averages of Barlow and Gerrodette's (1996) and Barlow's (1997) large delphinid $f(0)$ values were used for the middle region. Wade and Gerrodette (1993) calculated an $f(0)$ for killer whales in

the ETP, which we used to analyze the data from this region. We also used the ETP $f(0)$ in our analysis of the Gulf region because Gerrodette and Palacios (1996) did not estimate this parameter.

***Globicephala* species**

The data from the visual surveys contain three categories for the genus *Globicephala*: *Globicephala macrorhynchus*, *Globicephala melas*, and *Globicephala* species. Our analysis of the *Globicephala* data were similar to those that we described for *Orcinus orca* above. We stratified the *Globicephala* sightings by group size for analyses of the two northernmost regions, but pooled all data with respect to group size for the ETP and the Gulf. To estimate the density and abundance in all three categories of *Globicephala*, we used the estimates of $g(0)$ from Barlow (1995). Because the ETP and the Gulf were not stratified by group size, only the $g(0)$ value for large groups of large delphinids was used to analyze those regions. The $f(0)$ for our analysis of the northern region came from Barlow (1995), and for the middle region we used weighted averages of Barlow and Gerrodette's (1996) and Barlow's (1997) $f(0)$ for large delphinids. The ETP analysis incorporated Wade and Gerrodette's (1993) $f(0)$ for *Globicephala*. Gerrodette and Palacios (1996) reported an $f(0)$ for *Globicephala macrorhynchus* that we used to produce density estimates for the Gulf.

Unidentified Dolphin

We treated sightings assigned to the unidentified dolphin category as if they were small dolphin sightings, stratifying them by group size for analyses of the northern two regions, but pooling the data with respect to group size for analyses of the two southernmost regions. The $g(0)$ values that we used in these analyses were from Barlow (1995), using only the value calculated for groups of small dolphins greater than 20 individuals to analyze the ETP and the Gulf. The $f(0)$ values are from Barlow (1997) for the northern region, weighted averages of Barlow and Gerrodette (1996) and Barlow (1997) for the middle region, weighted averages of all dolphin species listed in Wade and Gerrodette (1993) for the ETP, and Gerrodette and Palacios' (1996) unidentified dolphin value for the Gulf.

Phocoenidae

***Phocoena phocoena*, Harbor Porpoise**

Harbor porpoise sightings were limited to waters north of 35°N, thereby including only the two northernmost regions in our study. The survey methods employed during the cruises included in this report were not suited to produce reliable density and abundance estimates of this nearshore, cryptic species. Therefore, we excluded harbor porpoises from our analysis.

***Phocoena sinus*, Vaquita**

The vaquita is a harbor porpoise species found only in the Gulf of California. We used Jaramillo-Legorreta *et al.*'s (1999) estimates of vaquita density and abundance, which they derived from boat surveys conducted during the summer of 1997, designed specifically for vaquitas.

***Phocoenoides dalli*, Dall's Porpoise**

Like the harbor porpoise, Dall's porpoise are found primarily in northern waters. No Dall's porpoise sightings occurred south of 35°N, so we limited our analysis to the northern and middle regions.

Barlow (1995) considers the Dall's porpoise to be a cryptic species, and we used his estimate of $g(0)$ for this species. Density estimates in the northern region were based on $f(0)$ values from Barlow (1997) for cryptic species. We calculated a weighted average of the $f(0)$ estimates for cryptic species from Barlow and Gerrodette (1996) and Barlow (1997) to use in our analysis of the data from the middle region.

III. Results

The four regions in the study area encompass over 25 million km² of the Pacific Ocean, including all or part of ninety-six 5° squares. More than 200,000 km of transect line were surveyed in Beaufort 0-5 seas and 30,000 km in Beaufort 0-2 conditions during the nine cruises contained in this analysis (Figures 2 and 4). The geographic strata around the western and southern margins of the survey area contained the lowest survey effort, whereas the coastal strata in all regions had the heaviest survey effort. The density estimates for each species or species group follow. It is important to remember that the results listed below reflect only those sightings that occurred under the specific Beaufort sea state and truncation distance restrictions determined by the use of a given estimate of $f(0)$; some sightings were not included in this analysis because they did not fall within those constraints.

Balaenopteridae

***Balaenoptera acutorostrata*, Minke Whale**

Ten minke whale sightings were reported under conditions of Beaufort 0-2 in the study area, all of which were from the northern and middle regions (Figure 9, Table 2). The greatest density of minke whales was observed in the waters off northern California/southern Oregon (geographic stratum A), and was estimated at 0.4 individuals per thousand square kilometers.

***Balaenoptera edeni*, Bryde's Whale**

Bryde's whales were found throughout the study area in densities ranging from 0.1 to 4.3 individuals per thousand square km (Figure 10, Table 3). The highest density of Bryde's whale sightings occurred in the Gulf of California and in the ETP region, from 15°N to 10°S, and from 140°W to the coast of Central and South America. Thus, the greatest number of Bryde's whales were observed in equatorial and coastal waters, with a decreasing trend in abundance with increasing distance offshore. Figure 10 also includes sightings from the category "Bryde's/sei whales," although, based on the low number of positive identifications of sei whales, it is likely that the majority of the unidentified sightings were Bryde's whales.

***Balaenoptera borealis*, Sei Whale**

One sighting was positively identified as a sei whale. That sighting occurred off the coast of northern California, in the merged stratum 35/36, during the 1993 PODS cruise. It resulted in a density estimate of 0.1 sei whales per thousand km².

***Balaenoptera physalus*, Fin Whale**

Fin whales were found in the northern, middle, and Gulf regions in waters north of 25°N. Density estimates ranged from 0.3 to 10.3 individuals per thousand km² (Figure 11, Table 4). The highest

density of fin whale sightings was reported in the northern Gulf of California (stratum 182), with slightly lower densities off the coast of California, and low densities north of 40°N.

***Balaenoptera musculus*, Blue Whale**

Blue whales were found in a wide band along the western coast of the Americas, from 45°N to 10°S (Figure 12, Table 5). Estimates of blue whale density ranged from 0.1 to 5.0 whales per thousand km², with the greatest number of individuals sighted off the coast of California and the northern Baja peninsula, and at the southern tip of the Baja peninsula. Blue whales appear to be continuously distributed off Oregon and California, but our data show a more patchy distribution in the ETP. Blue whales were not sighted west of 120° W in the ETP, and they were not sighted in the Gulf of California.

***Megaptera novaeangliae*, Humpback Whale**

Humpback whale sightings were patchy, with density estimates ranging from 0.1 to 6.9 whales per thousand km² (Figure 13, Table 6). Highest densities of humpback whales were sighted in the nearshore waters of California, central Baja (off the Pacific coast), and Colombia, with fewer sightings in the offshore waters of California, in the southern Gulf of California, and in the coastal waters of Panama and Ecuador. There were no sightings of humpback whales west of 115°W in the ETP.

Physeteridae

***Physeter macrocephalus*, Sperm Whale**

Sperm whale sightings extend across the study area from the northern boundary at 49°N to the southern limit at 15°S, and from the coastal waters off the Americas to 155°W in the subtropical gyre (Figure 14, Table 7). Estimates of sperm whale density ranged from 0.1 to 15.2 individuals per thousand km². The highest density estimates came from the coastal waters of Ecuador and Peru (geographic strata 218, 219, and 220). Moderate densities of sperm whales were observed in the nearshore waters throughout the study area and in the southern Gulf of California. In the ETP region, there appear to be greater densities in the eastern half of the study area, from 120°W to the coast.

***Kogia* species**

The range of density estimates for cetaceans of the genus *Kogia* covers two orders of magnitude, from 2.0 to 50.1 whales per thousand km² (Table 8). *Kogia* sightings spanned a wide latitudinal range, with sightings throughout the middle and ETP regions, and in the southern Gulf of California (Figure 15). The greatest numbers of *Kogia* were sighted off the coast of Central America, and their distribution extended in moderate to high densities offshore along a band of water centered on 10°N, stretching out to 140°W. Moderate densities were also sighted off Colombia, Ecuador, and Peru.

Ziphiidae

Large Beaked Whales

The large beaked whales in our analysis include Baird's (*Berardius bairdii*) and Cuvier's (*Ziphius cavirostris*) beaked whales and the tropical bottlenose whale (*Indopacetus pacificus*?). We will discuss the *Z. cavirostris* results separately from those of the other two whales because analysis of *Z. cavirostris* was limited to sightings conducted under calm seas. *Z. cavirostris* sightings covered the map,

with the conspicuous exception of the coastal waters off South America, geographic stratum P (Figure 16, Table 9). *Z. cavirostris* density estimates are greatest for the southern Gulf of California (38 whales/1000 km²) and a band along the equator bounded by 5°N and S (stratum N, 13 whales/1000 km²). The lowest estimate of *Z. cavirostris* density (0.3 whales/1000 km²) came from stratum E, located at the southwestern tip of the Baja peninsula. Although *B. bairdii* and *I. pacificus*(?) were found from the equator to 45°N (Figure 17), the sightings of these two species did not overlap spatially: *B. bairdii* sightings were restricted to waters North of 25°N, and all of the *I. pacificus*(?) sightings were South of 25°N. Of these two species, the *B. bairdii* densities are the greatest, with 1.2 whales/1000 km² estimated for stratum 71 and 1.0 whales/1000 km² in stratum 46 (Table 10). The lowest density estimate for *B. bairdii* was 0.1 whales/1000 km² in stratum 72. *I. pacificus*(?) density estimates ranged from 0.2 to 0.4 whales/1000 km². Neither *B. bairdii* nor *I. pacificus*(?) was sighted in the Gulf.

Small Beaked Whales

We included the pygmy beaked whale (*Mesoplodon preuvianus*), Blainville's beaked whale (*Mesoplodon densirostris*), *Mesoplodon* species "A", and unidentified *Mesoplodon* sightings in the category of small beaked whales. Estimates of small beaked whale densities ranged from 1 to 6.4 whales per thousand km² (Figure 18, Table 11). *Mesoplodon* whales are found in moderate densities throughout the middle region, in the southern Gulf of California, and in the ETP east of 130°W.

Delphinidae

With density estimates covering three orders of magnitude ranging from 10.5 to 2342.5 individuals/1000 km² (Table 12), the delphinids were the most numerous cetaceans in the study area, which is not surprising considering the large number of species included in the analysis and their ubiquity in the study area. Dolphins were found in every stratum surveyed (Figure 19). The majority of the study area was covered by densities in the 100-1000 individuals per thousand km² range. The highest densities were encountered in the southern California bight; off the west coast of the Baja peninsula; in the Gulf of California; in two strata due south of Guatemala; and in a 5° band of tropical waters anchored at the coast of Ecuador and continuing out to 100°W. The strata with the lowest densities of dolphins included the coastal waters off Washington and British Columbia, and the subtropical gyre waters around the Hawaiian Islands.

Phocidae

Of all strata containing porpoises, stratum 182 in the northern Gulf of California had the highest density of porpoises (approximately 142 porpoise per 1000 km²; Jaramillo-Legorreta *et al.* 1999), and all of the porpoise sightings in this region were identified as vaquita, *Phocoena sinus* (Table 13, Figure 20). Dall's porpoise, *Phocoenoides dalli*, was sighted in two geographic strata off Oregon and California in estimated densities of 3.6 and 115.8 animals/1000 km², the larger density being in stratum A. Estimates of total porpoise density are undoubtedly biased low because we did not include the harbor porpoise, *Phocoena phocoena*, in our analysis.

IV. Discussion

This paper provides a reanalysis of ship line-transect survey data of cetaceans in the eastern Pacific Ocean. Our goal was to describe the distribution and density or abundance patterns of 33 cetacean species over a wider oceanographic and geographic range than previous studies and at a spatial resolution comparable to the smallest scale previously explored ($5^{\circ} \times 5^{\circ}$). We divided a survey area encompassing over 25 million km^2 of ocean into approximately 5° or 10° squares, for each of which we estimated cetacean density and abundance. In comparison, Wade and Gerrodette (1993) divided the 19 million km^2 of the eastern tropical Pacific study region into four geographic strata for their analysis; Gerrodette and Palacios (1996) divided 3.9 million km^2 of EEZ waters off Central and South America into seven strata; Barlow and Gerrodette (1996) considered all of the waters up to 300 nmi offshore of California to be a single stratum; Barlow's (1997) analysis comprised two strata, the boundaries extending 300 nmi offshore of California and Oregon/Washington; and Koski *et al.* (1998) partitioned approximately 500,000 km^2 of waters in and around the Point Mugu Sea Range off California into strata ranging from approximately 3,400 km^2 to 300,000 km^2 .

There are several limitations, unknowns, and biases that must be understood or accounted for when interpreting analyses of cetacean distribution and density on small spatial scales. One major caveat is that sample sizes become very small when areas are finely stratified. For this reason, it is important not to interpret the low abundance or absence of a species in a particular 5° degree square as evidence that it does not occur there. Some common sense must be applied in interpreting patterns on this fine scale, and particular attention should be paid to the estimates of precision for each abundance estimate. Pooling some of the 5° squares, sacrificing spatial resolution for greater precision, was warranted in some cases. This was especially appropriate near the margins of the study areas, where sampling effort was least. We pooled squares so as to combine areas that tend to be most similar in oceanography. In the eastern tropical Pacific, oceanographic conditions vary most rapidly in a north-south direction, so 5° degree squares were combined first in an east-west direction. In contrast, along the coast of California, oceanographic conditions change more rapidly in an east-west (inshore-offshore) direction, so large-scale pooling (*i.e.*, for the Beaufort 0-2 species) was primarily in a north-south direction.

Estimation of the sighting probability function, $f(0)$, is one stage in the analysis of line-transect data in which significant biases may be introduced due to insufficient understanding of the factors affecting data collection or of the ecological system being studied. We used weighted averages of $f(0)$ in our analyses of species for which there was more than one applicable published value for a given region. In addition, if an $f(0)$ value was not available for a particular species or region, we either calculated a weighted average of $f(0)$ values from species with similar sighting characteristics, or we substituted an $f(0)$ value from one species/region for another. Furthermore, Wade and Gerrodette's (1993) published estimates of $f(0)$ for the ETP species were weighted averages of the $f(0)$ values that they estimated separately for each geographic stratum. Moreover, in some instances we used $f(0)$ values that were estimated for much larger oceanic areas than the geographic strata we used, yet we do not know the

temporal or spatial scale over which a given estimate of $f(0)$ is valid. One weakness in using values of $f(0)$ that were not estimated for a specific species, region, and survey is that we do not yet understand which factors affect the value of $f(0)$ or how they might interact to influence the detection probability function. The pertinent factors may be related to characteristics of the biology, ecology, or behavior of the observed species; they could be a function of environmental conditions that affect visibility at the time of a sighting; or they may be associated with characteristics of a given observer or the location of a particular sighting. It is most probable that $f(0)$ is affected by some combination of these factors. The parameter $f(0)$ is an important component in the line-transect formulas for estimating density and abundance. Further research into how to better estimate, or account for uncertainty in, this parameter is required.

Arguments similar to those presented above for $f(0)$ apply to $g(0)$, the trackline detection probability. One basic assumption of the standard line-transect methodology is that the probability of detecting an animal directly on the transect line equals unity or can be estimated (Buckland *et al.*, 1993). Barlow (1999) identifies two components which contribute to the value of $g(0)$ for cetaceans: 1.) whether an animal is at the surface and therefore available to be seen, and 2.) whether that animal is seen by an observer. Trackline detection probabilities have not been fully explored for all species or survey regions and, as a result, treatment of $g(0)$ varies among studies. For example, Wade and Gerrodette (1993) assumed that $g(0)$ was equal to 1.0 for their analysis of the ETP, whereas we relied upon Barlow's (1997 and 1999) estimates of $g(0)$ for all of our analyses. The subjectivity involved in assigning $g(0)$ values affects the resulting density or abundance estimates; however, we believe that using available $g(0)$ values is a better approach than assuming that $g(0)=1.0$, as is often done in such analyses.

Other remaining unknowns that currently impede efforts to create a predictive model of cetacean distribution and density include stock structure and seasonal variation. Biological stock structure was considered for only spinner, common, and spotted dolphins. Even for these species, however, one could argue that the stock structure we used (which was dictated by the resolution of the data) does not adequately define biological populations of these dolphins. In addition, we did not address seasonal variation in cetacean distribution or density because all of the data used in this study were collected on research cruises conducted during the summer and autumn months. Nevertheless, our database represents the best scientific information available for cetaceans in the eastern Pacific Ocean. One could make educated guesses about the large-scale variations in distribution that are likely for some species of cetaceans, but the data necessary to describe -- let alone predict -- seasonal patterns in the survey area are not currently available.

When incorporating our results into a system such as LMRIS, which considers our geographic strata as puzzle pieces that may be pooled to provide a glimpse at estimated cetacean densities on larger spatial scales, it is important to be aware of three known biases. First, the data that we analyzed included several categories for sightings that could only be identified to the level of genus, family, or order. If one is interested in obtaining an estimate of the total density of cetaceans in a particular geographic region, those "unidentified" categories must be included or the resulting density estimate will be biased low. Second, a

statistical bias arises when combining parameter estimates together, for example, to estimate cetacean density in a region comprising several geographic strata. An analytical solution to this pooling bias is explained in Appendix A. Finally, pooling may also bias estimates of the variability in the data, such as the coefficient of variation (CV). Appendix B addresses the problem of bias in the CV, including how to correctly compute a CV for pooled data.

In conclusion, this report represents a first attempt to look at meso-scale patterns of cetacean distribution and abundance. We anticipate that our understanding of these meso-scale patterns can be greatly improved by modeling species distributions as functions of oceanographic and geographic variables. Work is ongoing in this area.

V. Acknowledgements

We would like to thank the visual observers, cruise leaders, crew, and officers who have devoted many days, months, or years at sea to collecting the wealth of data that we used in this study. We would also like to thank J. Carretta for introducing us to Surfer, and T. Gerrodette, T. Norris, and S. Reilly for their helpful comments on earlier drafts of this report.

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VII. Appendix A

A purely probabilistic bias must be accounted for in the following situations: when 1.) comparing density and abundance estimates produced by analyses performed on different spatial scales, and 2.) adding individual small-scale estimates together to obtain a value for a larger area. The line-transect formula for estimating density and abundance contains variables for area (only when estimating abundance), number of sightings, $f(0)$, and group size in the numerator, and variables for $g(0)$ and length of survey effort in the denominator. In our study, we applied the line-transect formula to the data for individual species from individual geographic strata to produce a separate density estimate for each species within each stratum. Using our estimates, one could calculate an overall estimate of cetacean abundance for all geographic strata combined or for a sample of the strata included in this study by simply adding all of the individual abundance estimates together. We will refer to this as the "additive method." The total abundance estimate derived by the additive method, however, will not be the same as one produced using identical data that were added together *before* insertion into the line-transect formula, hereafter called the "pooling method," even if the same $f(0)$ and $g(0)$ values are used for all estimates. The pooling method is analogous to the case of considering the entire survey area as one large geographic stratum and combining all of the data for the desired species from the beginning of the analysis. The difference in the abundance estimates produced by the additive and pooling methods is due to the fact that the expectation of a ratio of random numbers is not equal to the ratio of their expectations. (Although variables such as group size, transect length, and number of sightings are not completely "random," they include a large component of random (stochastic) variability.)

Consider the simplified scenario in which there is only a single species, and the only variables involved in the abundance estimate are n , the number of sightings; a , the area of the geographic stratum; and L , the length of the trackline. Two lines of reasoning can show that

$$E\left(\frac{na}{L}\right) > \frac{[E(n)E(a)]}{E(L)},$$

where $E(x)$ is the expected value of the variable x . This says that the expected value derived from the additive method is greater than that from the pooling method. The ratio of expectations (the expected value from the pooling method), is equal to the arithmetic mean of the numerator divided by the arithmetic mean

of the denominator, where the arithmetic mean is computed as

$$\frac{\sum x}{n}.$$

Goodman (1984) states that, if the errors are independent, the expectation of the ratio (*i.e.*, the expected value from the additive method) will be the ratio consisting of the arithmetic mean of the numerator divided by the harmonic mean of the denominator. The harmonic mean is equal to

$$\frac{n}{\sum \frac{1}{x}}.$$

The harmonic mean is smaller than the arithmetic mean of a given set of numbers. The result is that the denominator in the additive formula will be biased downward, so the final abundance estimate produced by the additive method will tend to be an overestimate of the true value. Because the only difference between the additive and pooling formulae lies in the denominator, we can limit the rest of the discussion to the length of the transect line, L . If Λ is the harmonic mean of the transect lengths, $\bar{L}$ is the arithmetic mean length, N_{add} represents the abundance estimate derived from the additive method, and N_{pool} equals the corresponding value from the pooling method, then

$$\frac{N_{pool}}{N_{add}} = \frac{\Lambda}{\bar{L}}$$

and, therefore,

$$N_{pool} = \left(\frac{\Lambda}{\bar{L}} \right) N_{add}.$$

Thus, to calculate the pooled estimate of abundance given the additive estimate of abundance, it is necessary to know the arithmetic mean length and the harmonic mean length of the sample. Goodman (1984) adds that the discrepancy between the harmonic and arithmetic means increases with the variance, as will be shown below. This implies that the variance in the length of transect lines surveyed in the geographic strata will affect the magnitude of the bias.

A Taylor series approximation may also be used to estimate the expected bias. The Taylor series approximation states that

$$E\left(\frac{1}{x}\right) \cong \frac{1}{\bar{x}} + \frac{1}{\bar{x}^3} [Var(x)],$$

where $\bar{x}$ refers to the arithmetic mean value of x . Probability theory allows for the following decomposition

$$E\left(\frac{na}{L}\right) = [E(n)][E(a)]\left[E\frac{1}{L}\right],$$

and we want to show that this is greater than

$$\frac{[E(n)][E(a)]}{[E(L)]}.$$

To do so requires only that we examine the behavior of L because the variables n and a cancel. Thus, the problem simplifies to showing that

$$E\left(\frac{1}{L}\right) > \frac{1}{[E(L)]}.$$

This indeed is true because

$$\frac{1}{[E(L)]} = \frac{1}{\bar{L}},$$

and from the Taylor series approximation we know that

$$E\left(\frac{1}{L}\right) \cong \frac{1}{\bar{L}} + \frac{1}{\bar{L}^3} [Var(L)].$$

It is therefore evident that the bias is a factor of $\frac{1}{\bar{L}^3} [Var(L)]$, namely

$$\frac{\frac{1}{\bar{L}^3} [Var(L)]}{\frac{1}{\bar{L}}}.$$

Furthermore, simple algebra shows that

$$\frac{N_{pool}}{N_{add}} = \frac{1}{\left\{1 + \frac{1}{\bar{L}^2} [Var(L)]\right\}},$$

thus,

$$N_{pool} = N_{add} \left\{ \frac{1}{1 + \frac{1}{\bar{L}^2} [Var(L)]} \right\}.$$

From the preceding discussion, it follows that the data required to use the Taylor series approximation to compute the magnitude of the bias resulting from using the additive method to derive an abundance estimate are: the transect length per geographic stratum, the area of each stratum, and the number of sightings per stratum. To simply calculate the pooled estimate of abundance from the additive estimate of abundance, however, it is sufficient to know the mean length and the variance in the length.

VIII. Appendix B

Calculating the CV or variance of a random variable that is comprised of several independent factors with their associated CV's or variances is relatively straightforward: variances of factors that are added together are additive, and the squares of CV's of factors that are multiplied together are additive. The following example demonstrates how to calculate a CV for N_{tot} , the estimate of total abundance, from a set of independent abundance estimates, $(N_1, \dots, N_n)$, as would be the case if you were to add the abundance estimates of n cetacean species in a given geographic stratum in order to calculate an estimate of the total abundance of cetaceans in that stratum.

Let

$$N_i = \frac{A_i n_i s_i f_i(0)}{2 L_i g_i(0)}$$

and let

$$N_{tot} = N_1 + N_2 + \dots + N_n.$$

If you know the CV's for the N_i , you can find $CV(N_{tot})$ by calculating and summing the variances:

$$CV(N_i) = \frac{\sqrt{Var(N_i)}}{N_i},$$

which means that

$$Var(N_i) = \left[CV(N_i) N_i \right]^2.$$

Furthermore, because the variances are additive,

$$Var(N_{tot}) = \sum Var(N_i).$$

Converting back to a CV is simple:

$$CV(N_{tot}) = \frac{\sqrt{Var(N_{tot})}}{N_{tot}}.$$

The calculation requires a few more steps if some of the factors included in the line-transect equation are dependent. Consider the case where $f(0)$ and $g(0)$ are dependent variables, *i.e.*,

$$f_1(0) = f_2(0) = \dots = f_n(0),$$

$$g_1(0) = g_2(0) = \dots = g_n(0).$$

We can write the equation for the total abundance estimate as follows:

$$N_{tot} = \frac{f(0)}{g(0)} \left[\frac{A_1 n_1 s_1}{2 L_1} + \frac{A_2 n_2 s_2}{2 L_2} + \dots + \frac{A_n n_n s_n}{2 L_n} \right].$$

For a given geographic stratum, A_i and L_i are constant and therefore they do not contribute to the variance. The terms $f(0)$, $g(0)$, n_i , and s_i will have associated variances or CV's. To simplify matters, assume that you are given $CV(ns_i/2L_i)$, where $ns_i/2L_i$ is the encounter rate. Because the relationship between $f(0)$, $g(0)$, and ns is multiplicative, the squares of their CV's add to produce the square of the CV for N_{tot} . Before we can

add the squared CV's, however, we must first calculate a value for the overall CV of the terms $\frac{A_i n_i s_i}{2L_i}$ inside the brackets in the equation above. Those terms are added together, and, therefore, their variances are additive:

$$Var\left(\frac{ns}{2L}\right) = \sum Var\left(\frac{n_i s_i}{2L_i}\right).$$

Remember that we are ignoring the A_i 's because they do not contribute to the variance in this case. Then the CV for the encounter rate is calculated as follows:

$$CV\left(\frac{ns}{L}\right) = \frac{\sqrt{Var\left(\frac{ns}{L}\right)}}{\left(\frac{ns}{L}\right)}.$$

Now we can sum the squared CV's:

$$CV^2(N_{tot}) = CV^2(f(0)) + CV^2(g(0)) + CV^2\left(\frac{ns}{L}\right).$$

The CV of N_{tot} can be found by taking the square root of the resulting value, and as we have seen above, the variance of N_{tot} is the square of the product of $CV(N_{tot})$ and N_{tot} .

If we were to calculate $CV(N_{tot})$ in the second example as we did in the first, we would have accounted for the CV's of $f(0)$ and $g(0)$ multiple times, thereby overestimating $CV(N_{tot})$. With a database as large as ours, it is very difficult – although not impossible -- to keep track of which parameters are dependent, and the bias resulting from treating them as if they were independent is relatively small. Therefore, for practical purposes associated with LMRIS, we recommend that this bias be understood yet ignored. The result will be a slight overestimation of the CV of a pooled region.

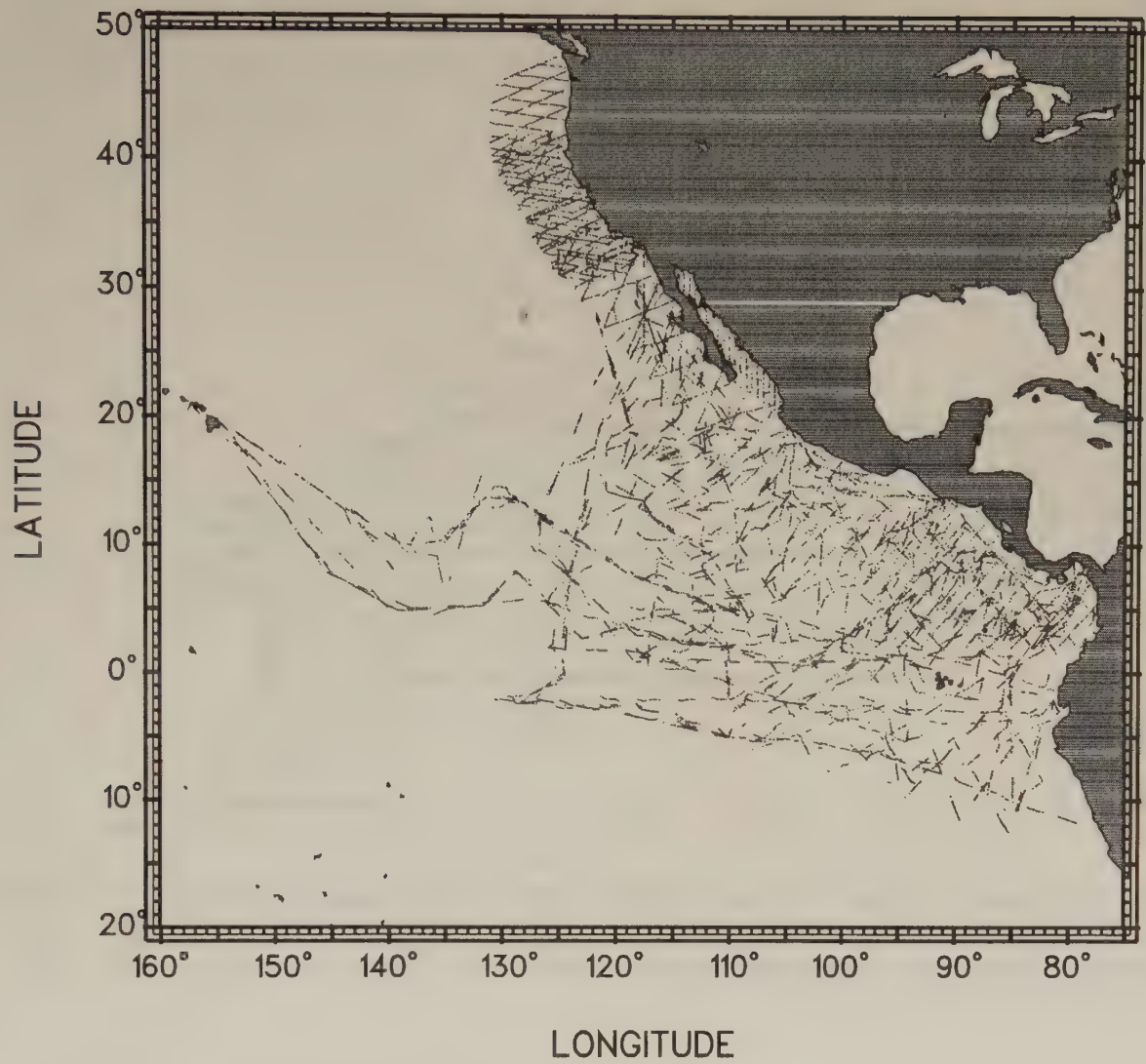


Figure 1. Transect lines covered during 1986-1996 research vessel surveys in the eastern Pacific Ocean.

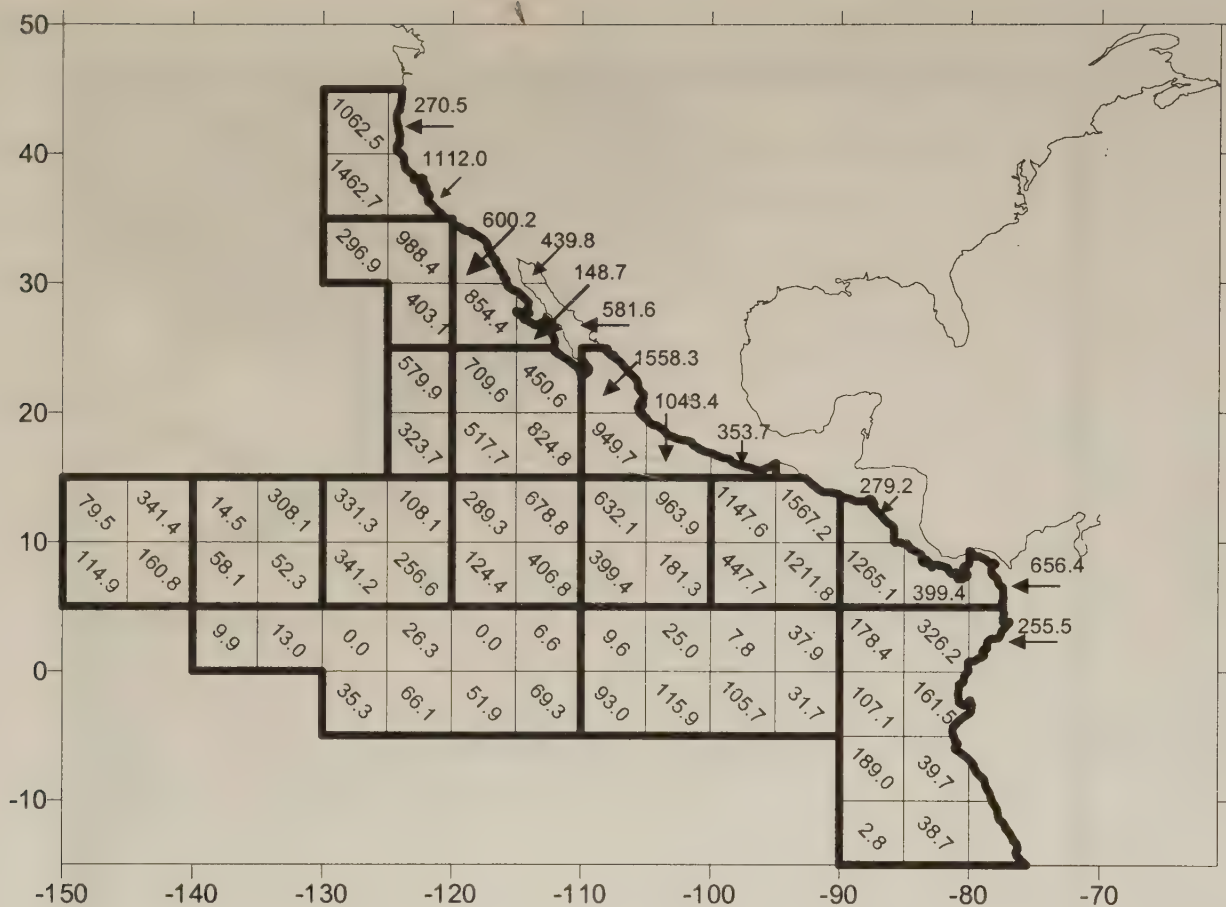


Figure 2. Length of transect line surveyed (km) within 5-degree squares in Beaufort 0-2 conditions during 1986-1996 summer/fall research vessel surveys. Heavy lines indicate boundaries of geographic strata used in Beaufort 0-2 analyses.

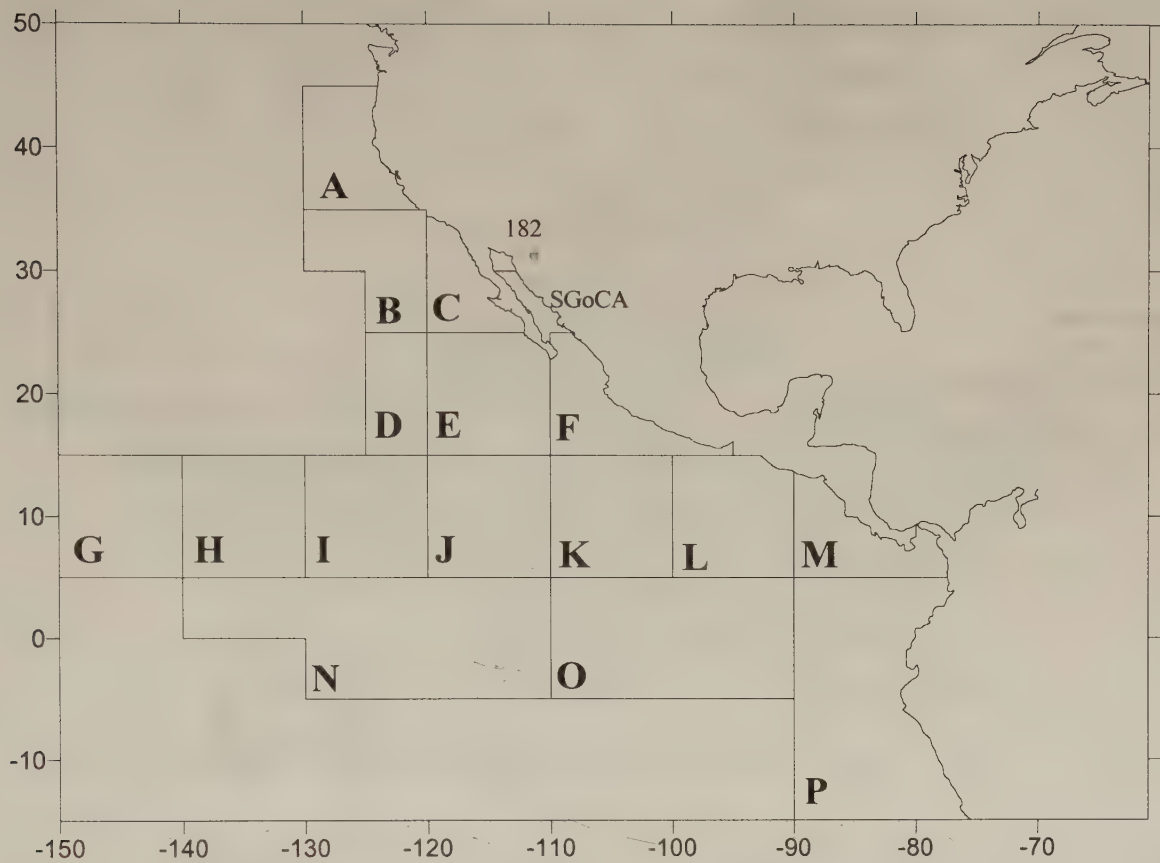


Figure 3. Geographic strata used in the Beaufort 0-2 analyses.

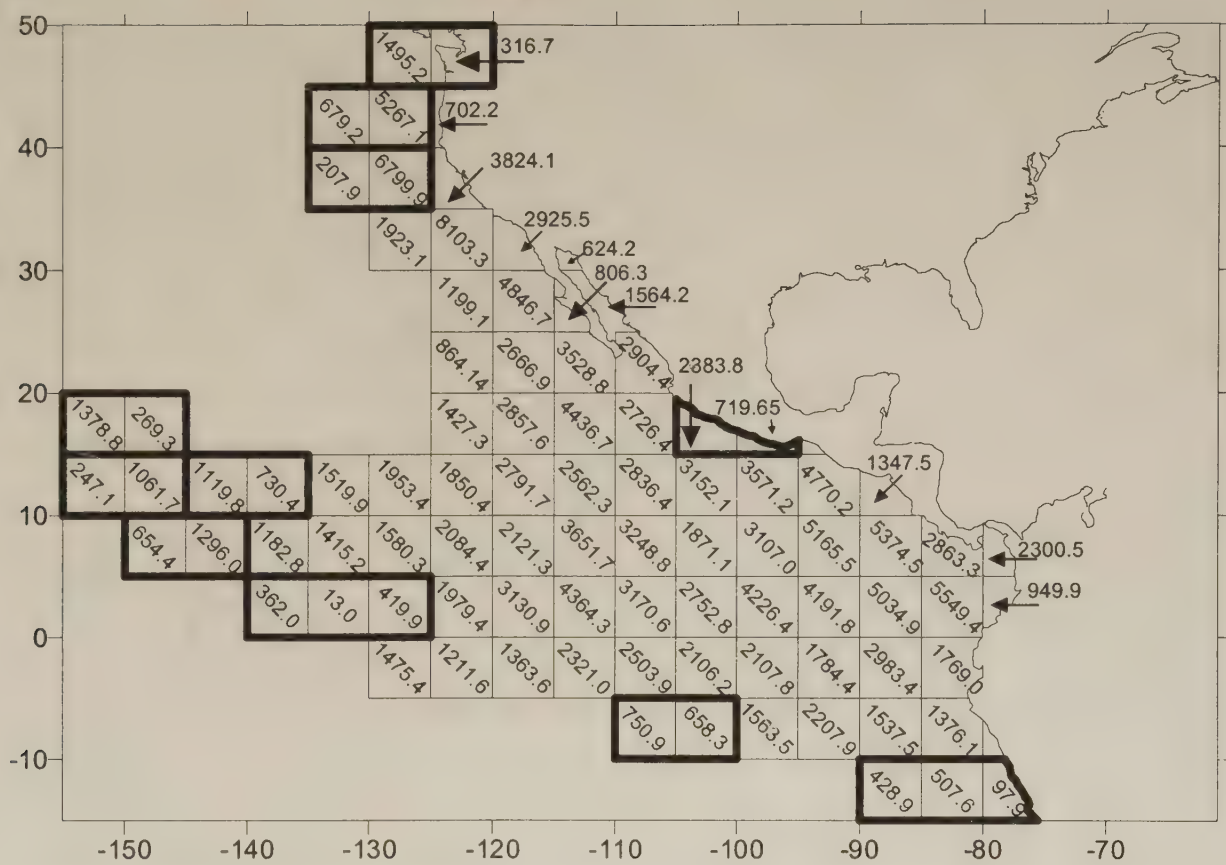


Figure 4. Length of transect line surveyed (km) within 5-degree squares in Beaufort 0-5 conditions during 1986-1996 summer/fall research vessel surveys. Heavy lines indicate boundaries of merged squares used in Beaufort 0-5 analyses.

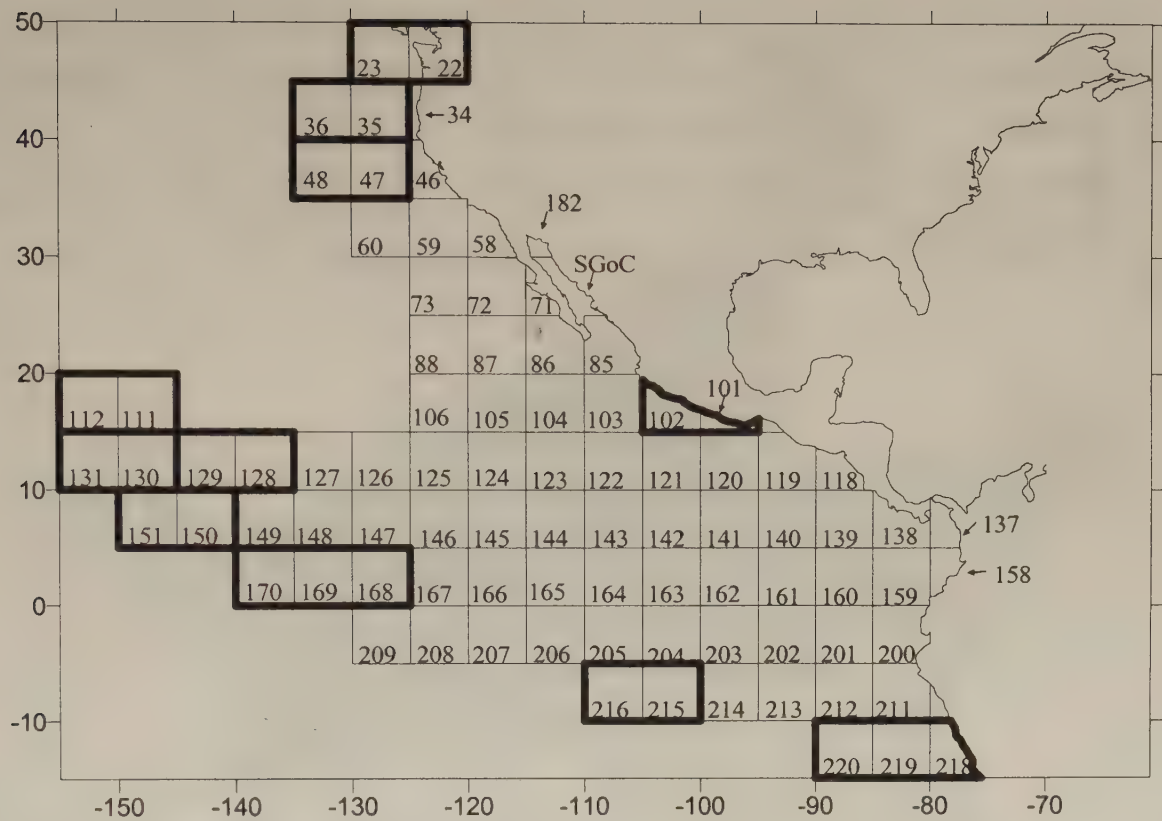


Figure 5. Geographic strata used in the Beaufort 0-5 analyses.

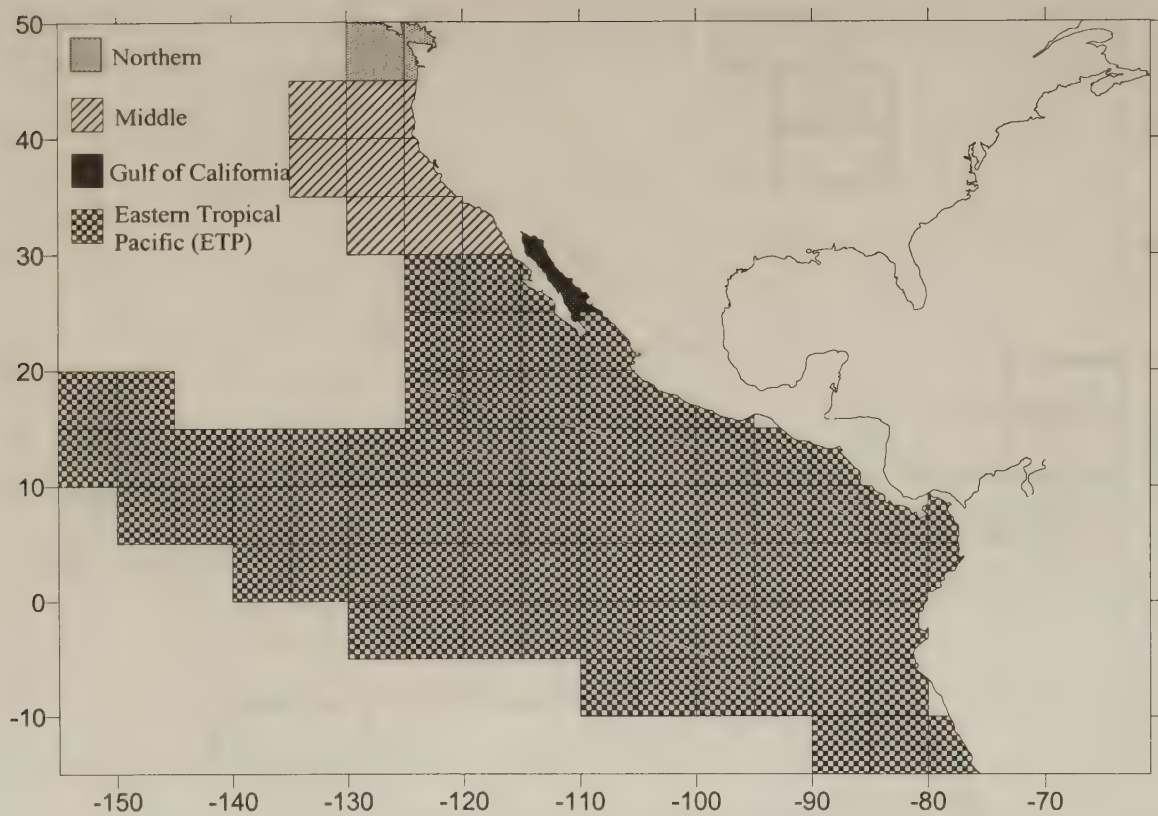


Figure 6. Survey regions in the eastern Pacific Ocean referred to in the text.

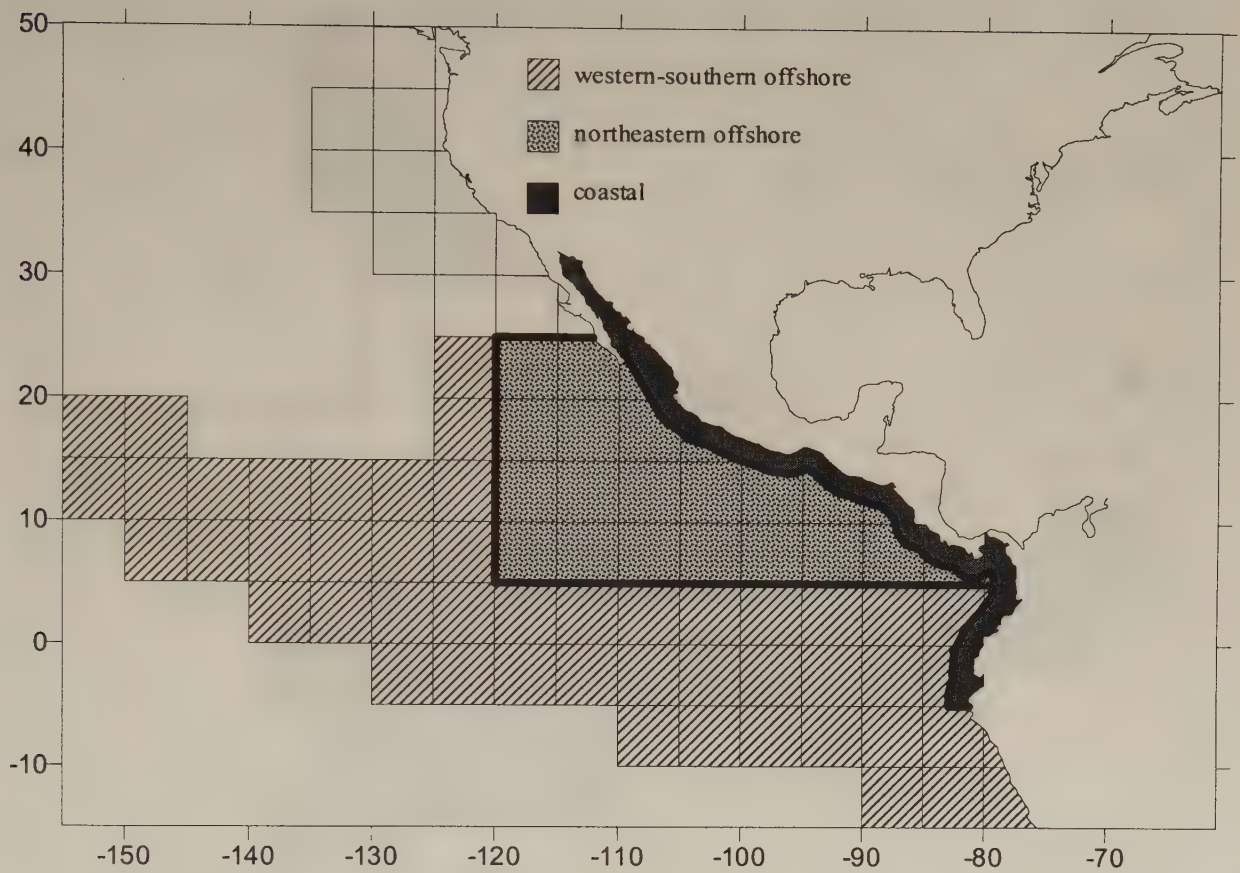


Figure 7. Stock boundaries for the spotted dolphin, *Stenella attenuata*, in the eastern tropical Pacific Ocean (Dizon *et al.*, 1994). Coastal and offshore stocks may exist in sympatry within 100 nmi of the coast.

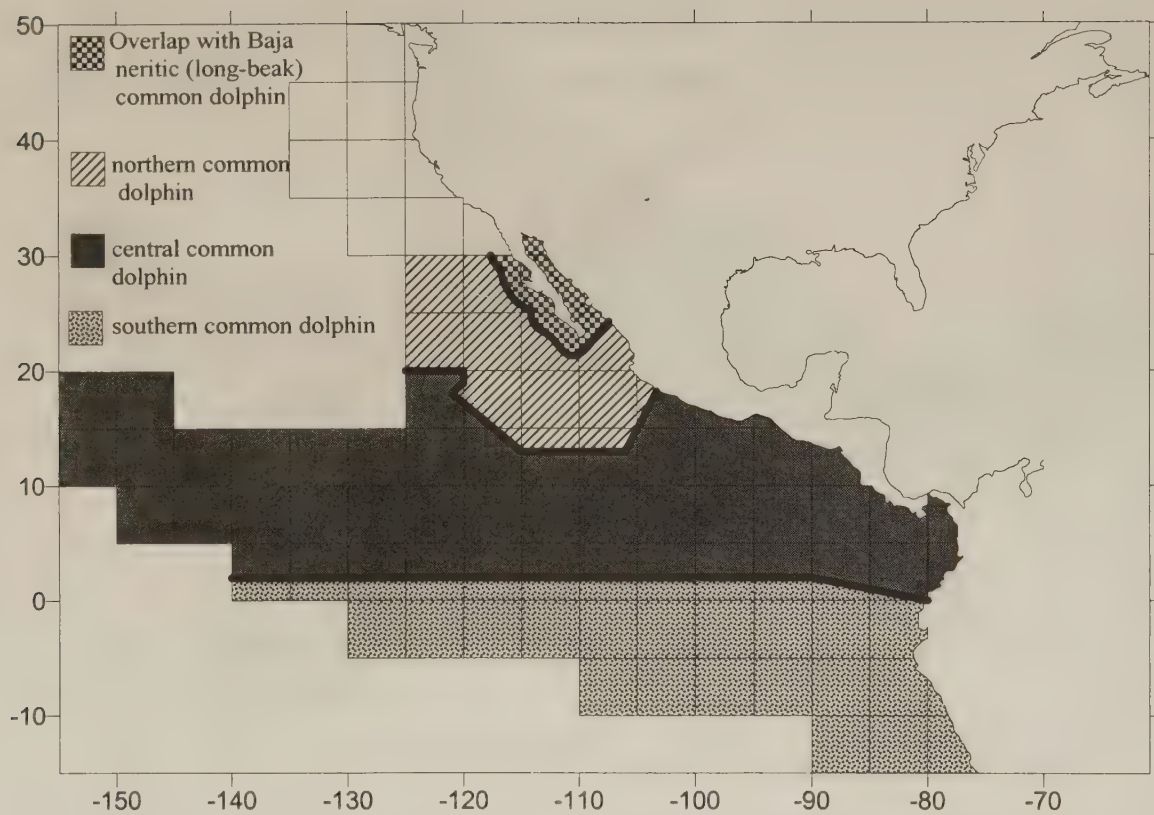


Figure 8. Stock boundaries for common dolphins, genus *Delphinus*, in the eastern tropical Pacific Ocean (Perrin *et al.*, 1985).

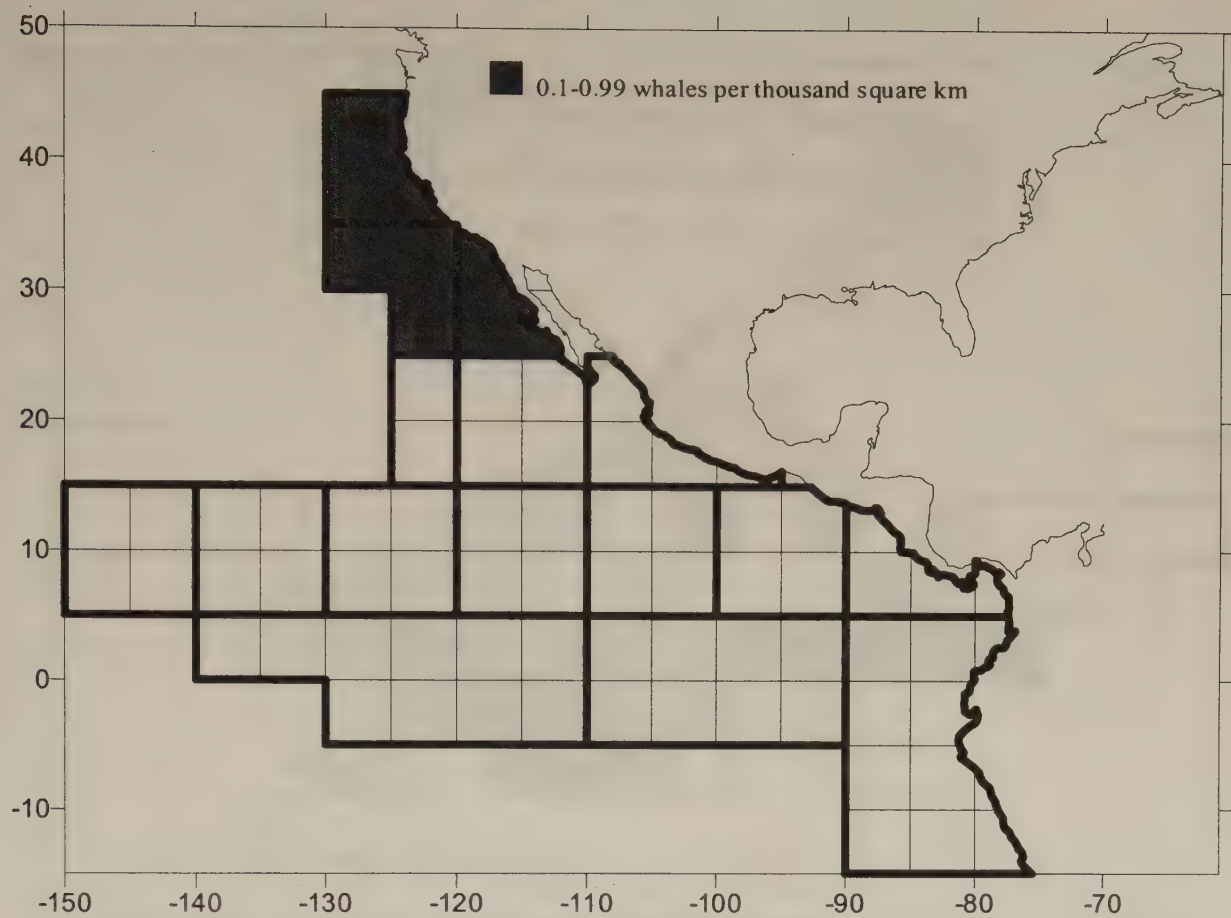


Figure 9. Minke whale, *Balaenoptera acutorostrata*, density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

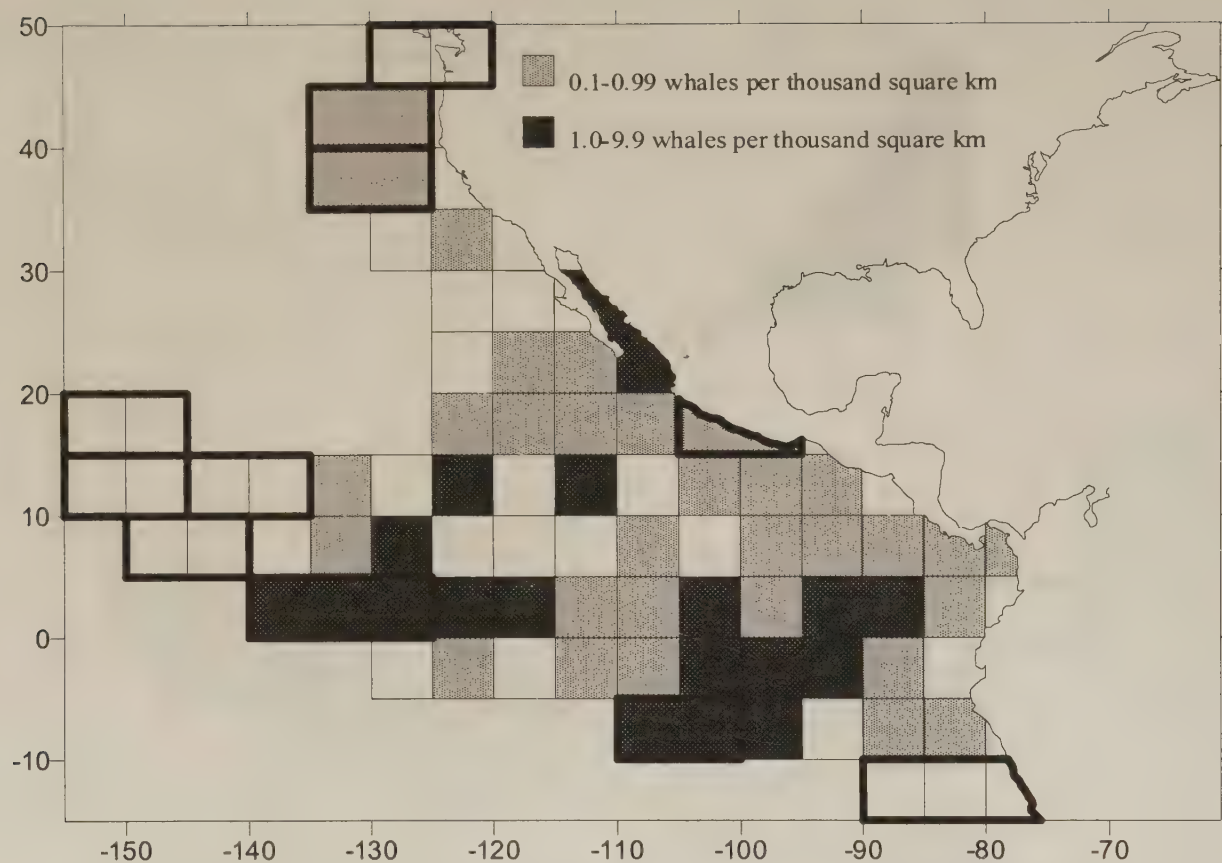


Figure 10. Bryde's (*Balaenoptera edeni*) and sei (*Balaenoptera borealis*) whale density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

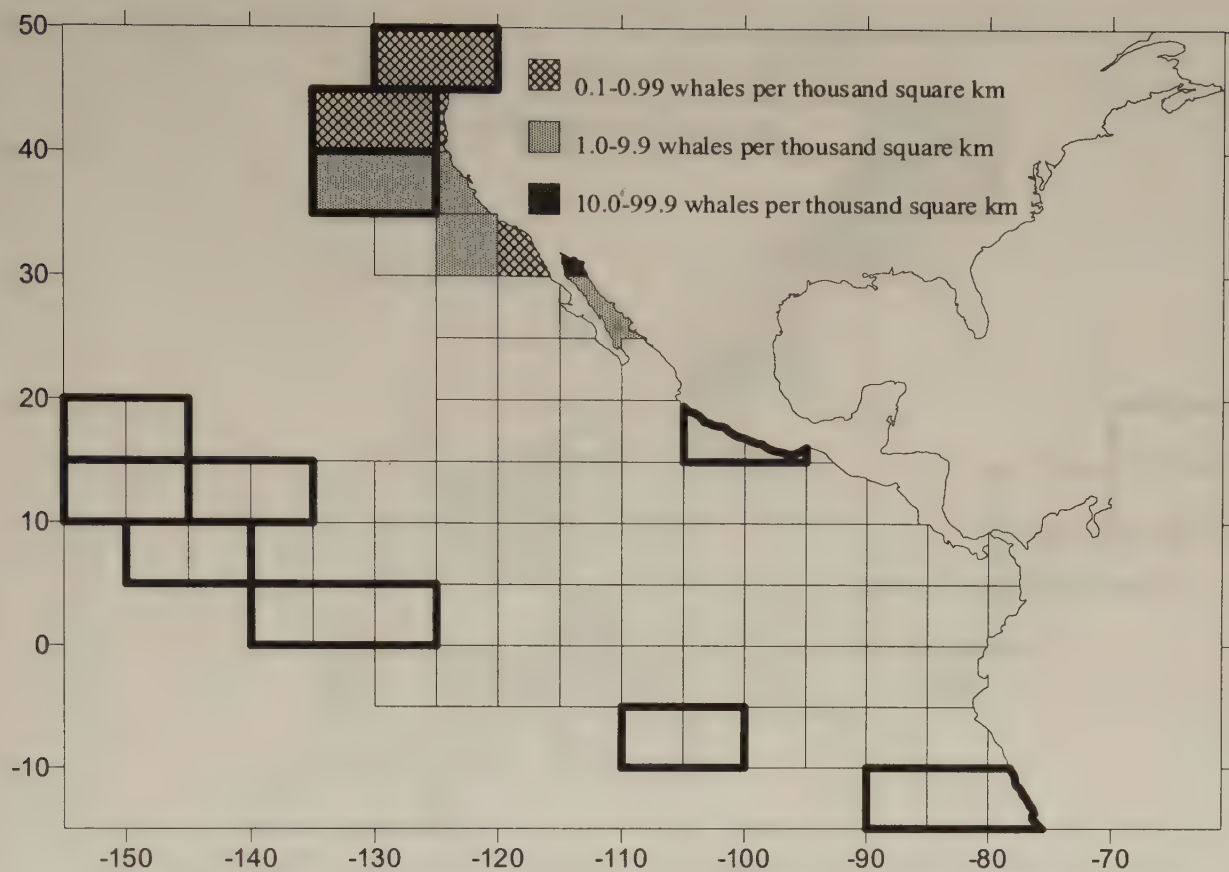


Figure 11. Fin whale, *Balaenoptera physalus*, density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

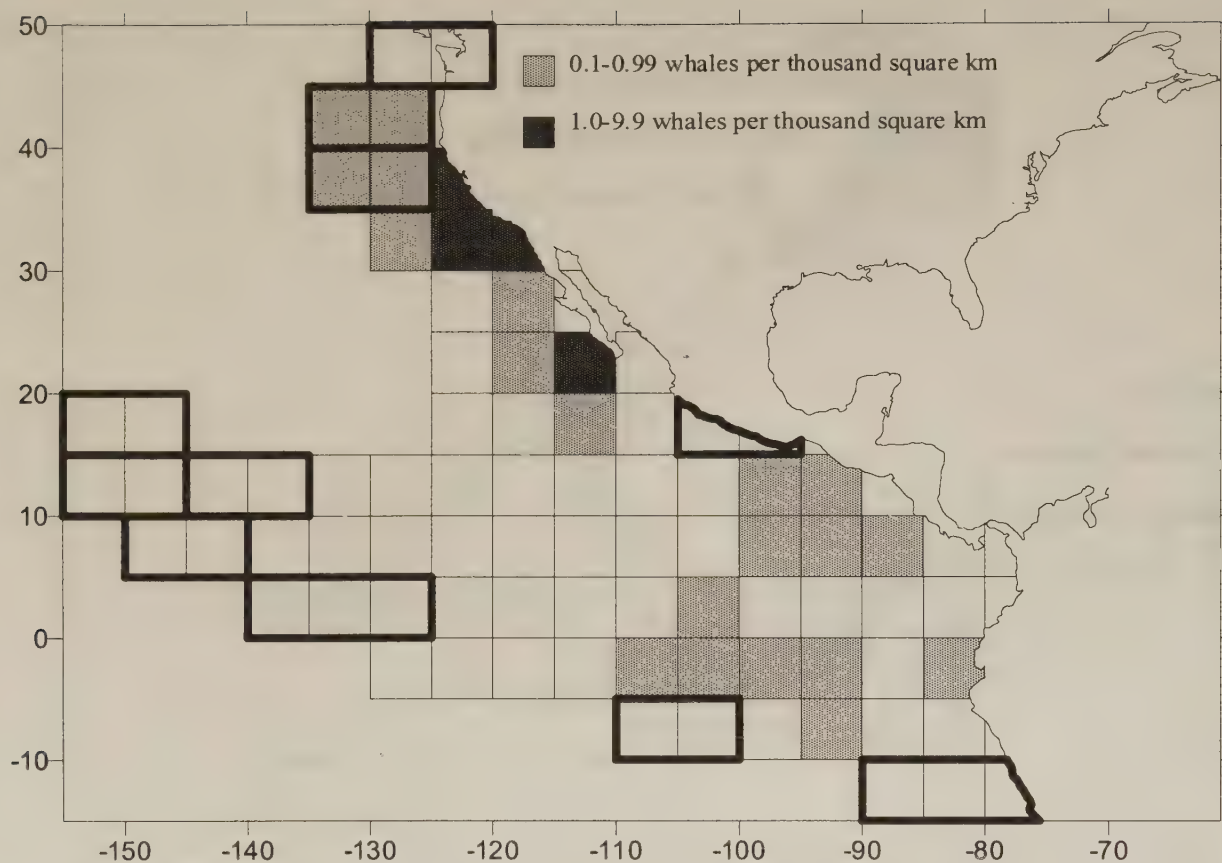


Figure 12. Blue whale, *Balaenoptera musculus*, density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

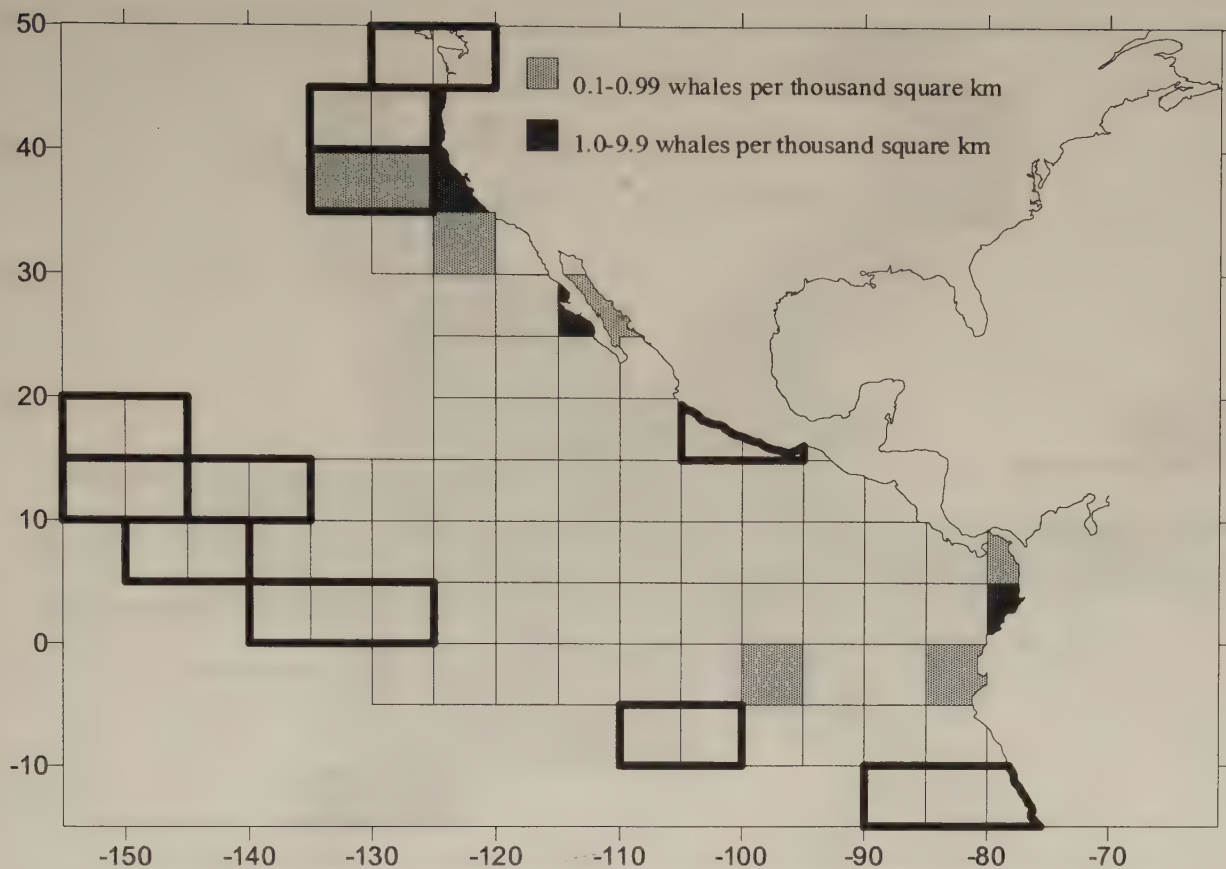


Figure 13. Humpback whale, *Megaptera novaeangliae*, density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

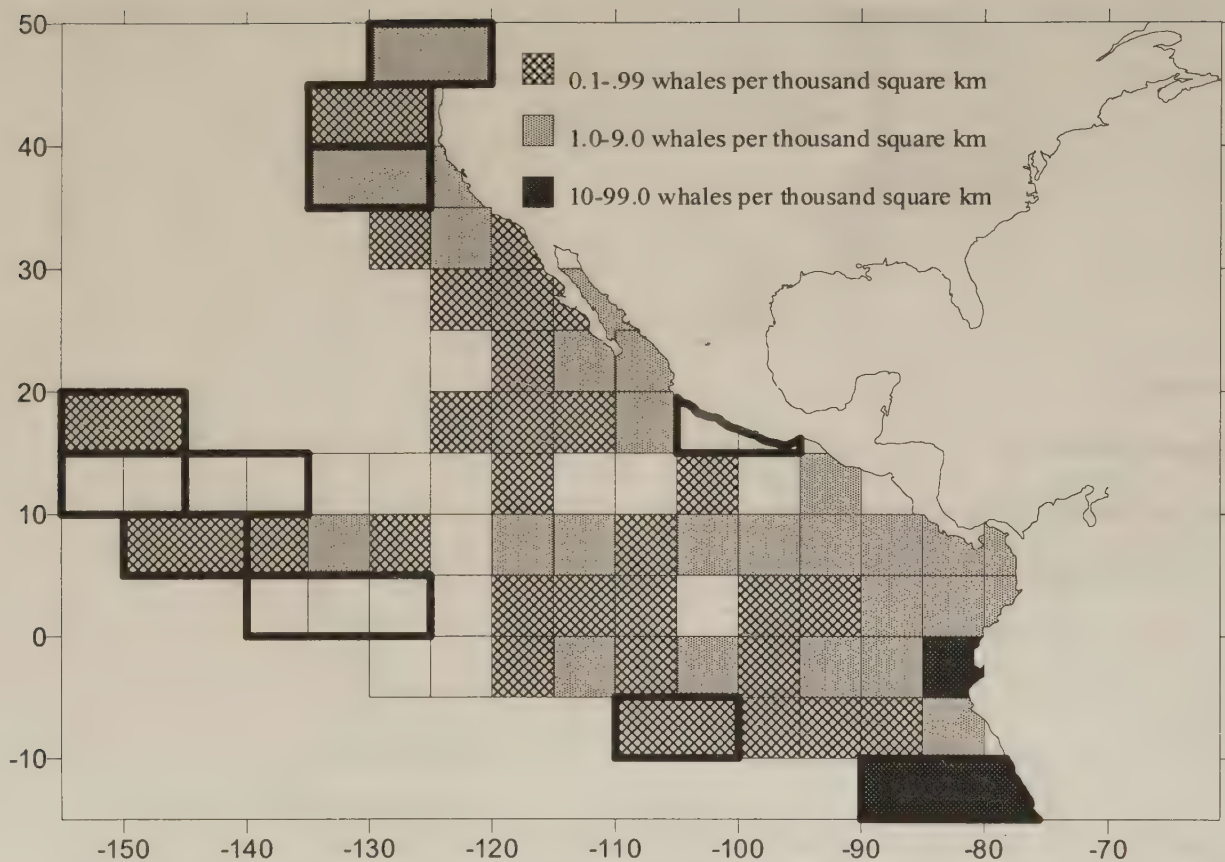


Figure 14. Sperm whale, *Physeter macrocephalus*, density in the eastern Pacific Ocean, based on 1986-1996 summer/ fall research vessel surveys. Blank squares contained no sightings.

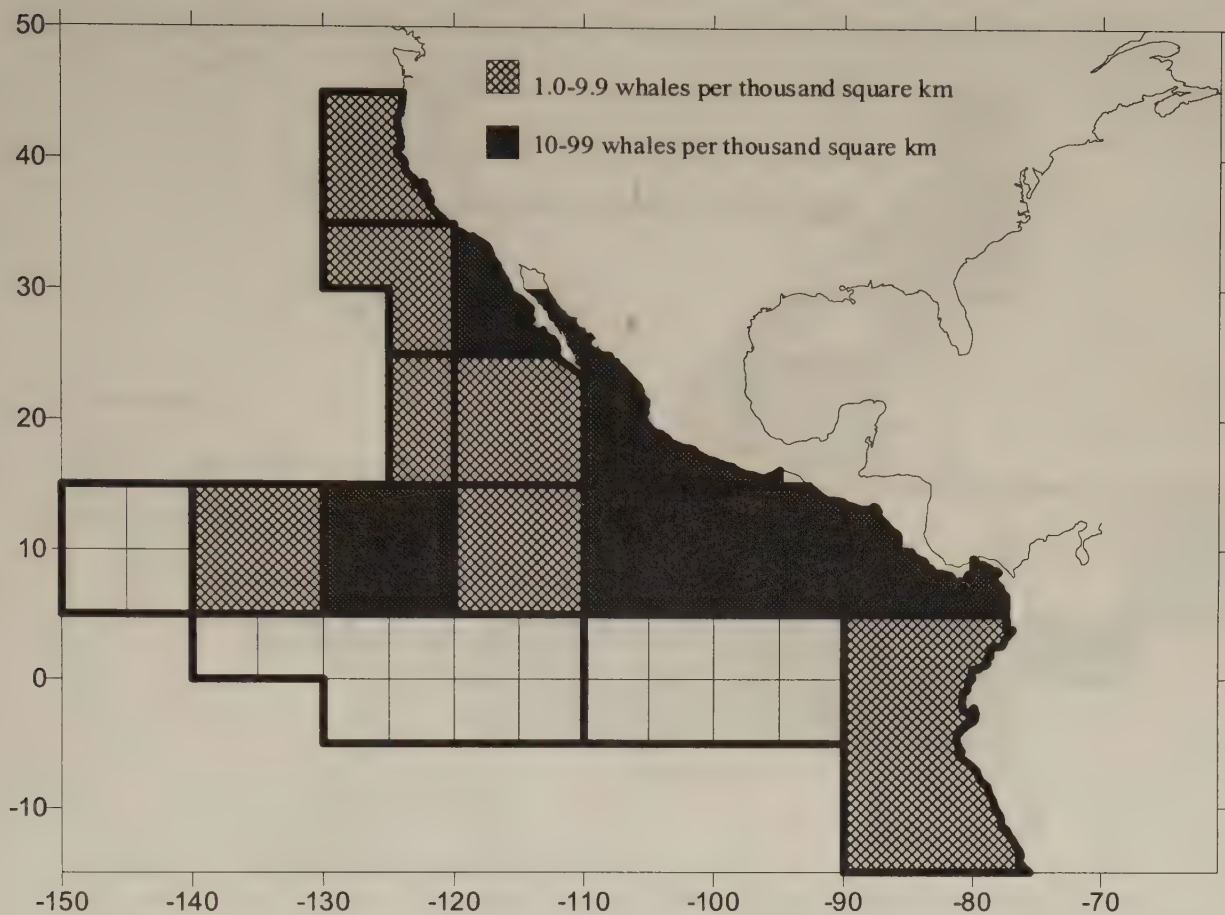


Figure 15. Dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whale density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

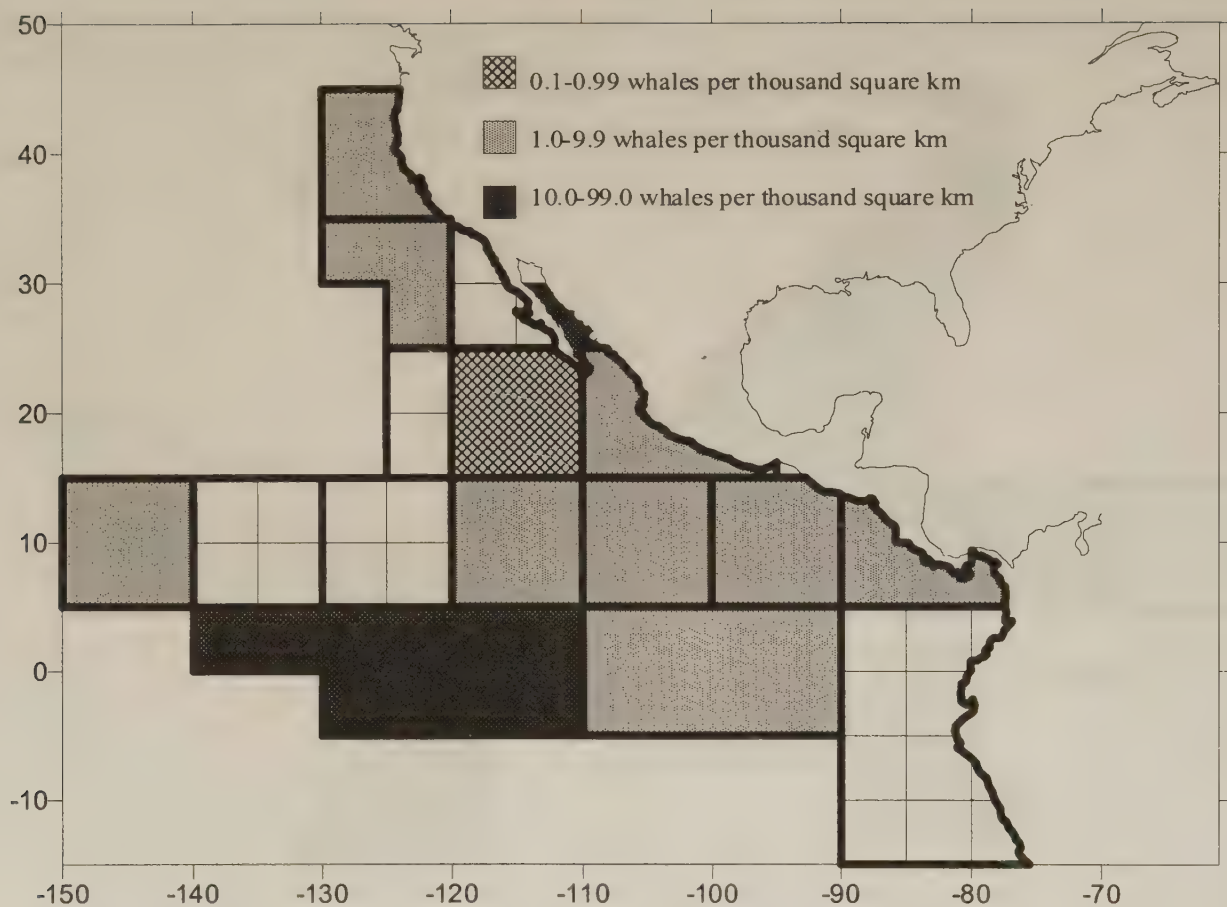


Figure 16. Cuvier's beaked whale, *Ziphius cavirostris*, density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

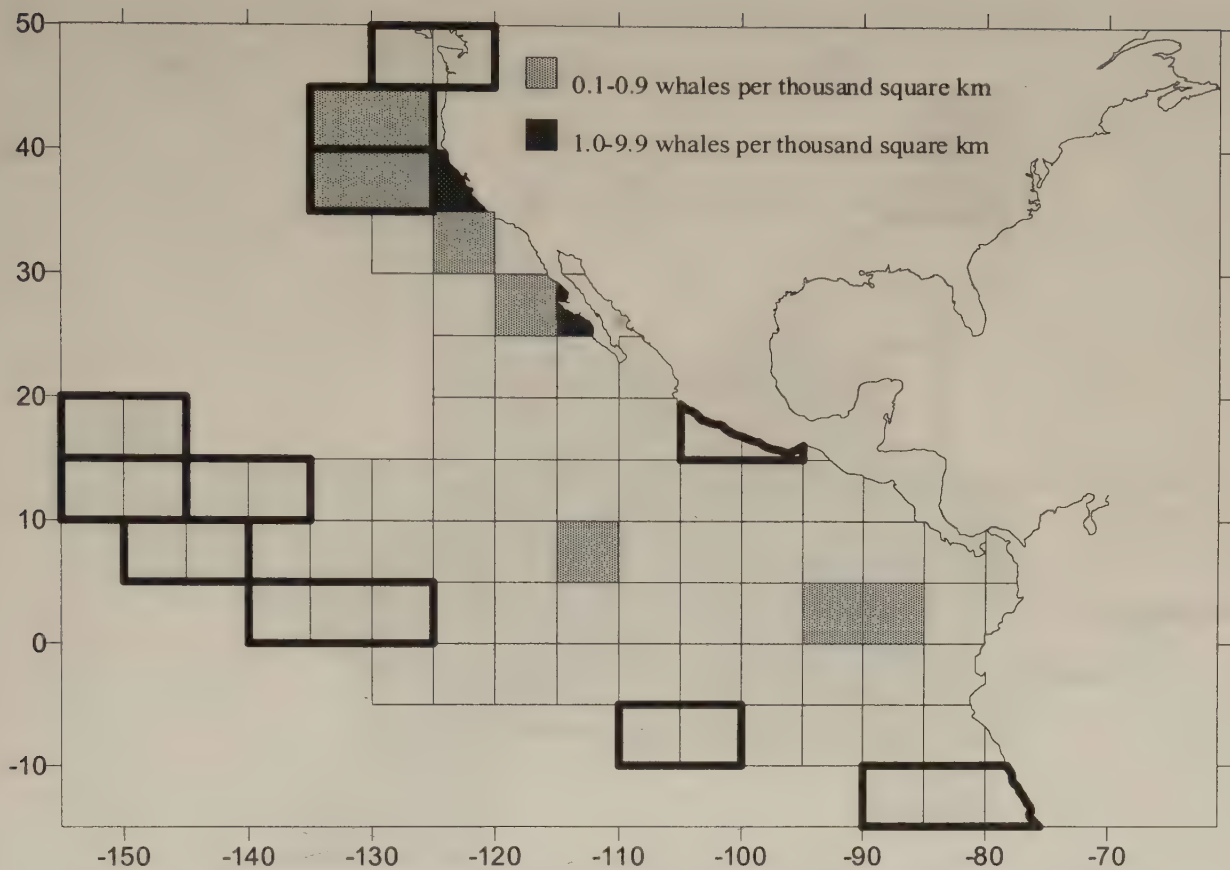


Figure 17. Density of Baird's beaked whales (*Berardius bairdii*) and tropical bottlenose whales (*Indopacetus pacificus*?) in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

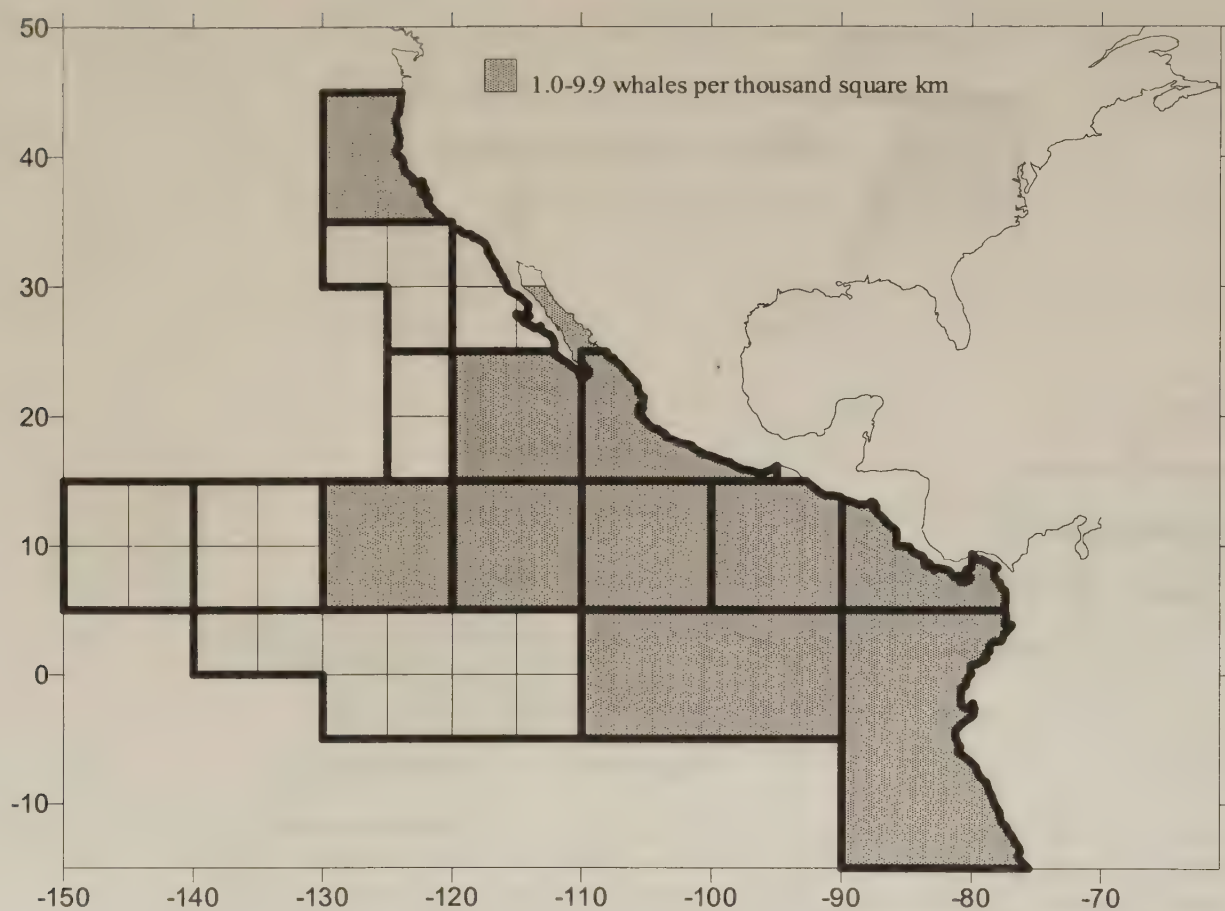


Figure 18. Small beaked whale (genus *Mesoplodon*) density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys. Blank squares contained no sightings.

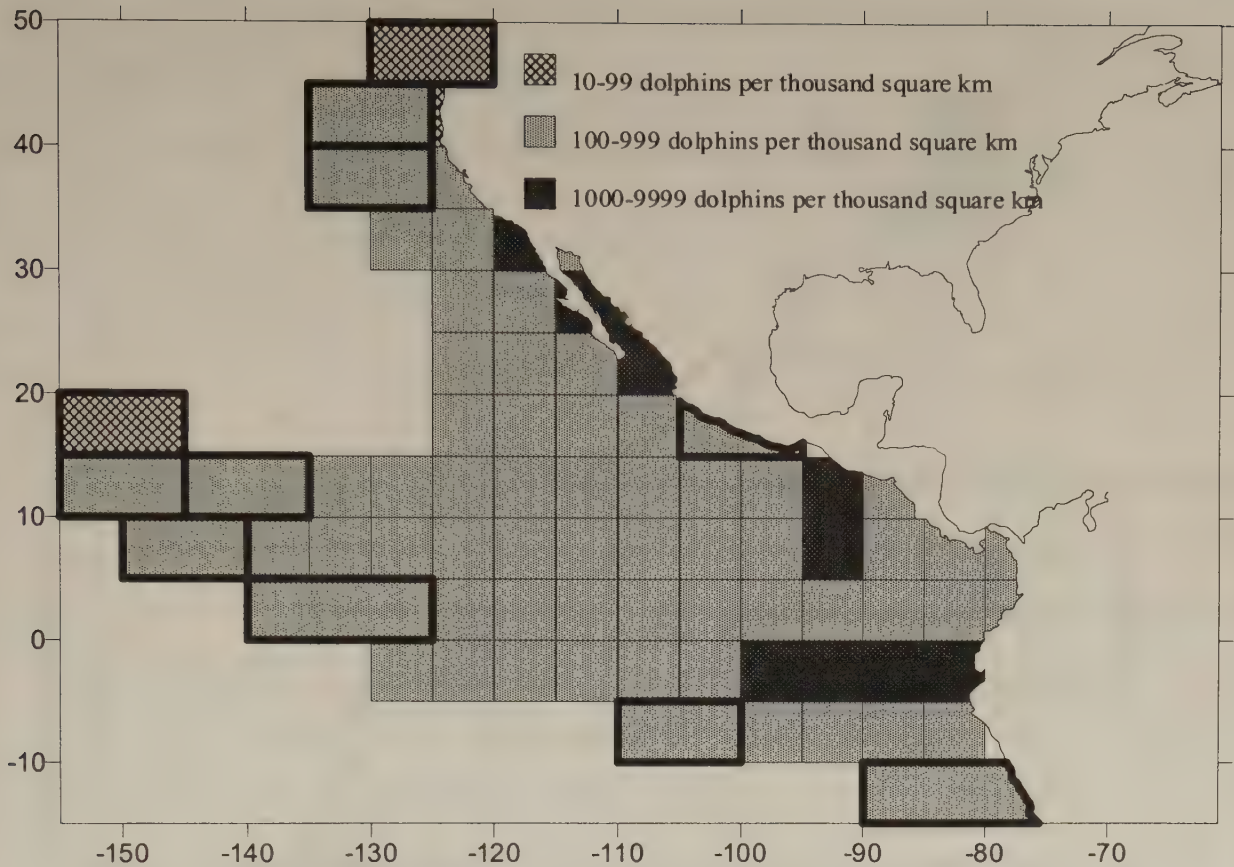


Figure 19. Dolphin (family Delphinidae) density in the eastern Pacific Ocean, based on 1986-1996 summer/fall research vessel surveys.

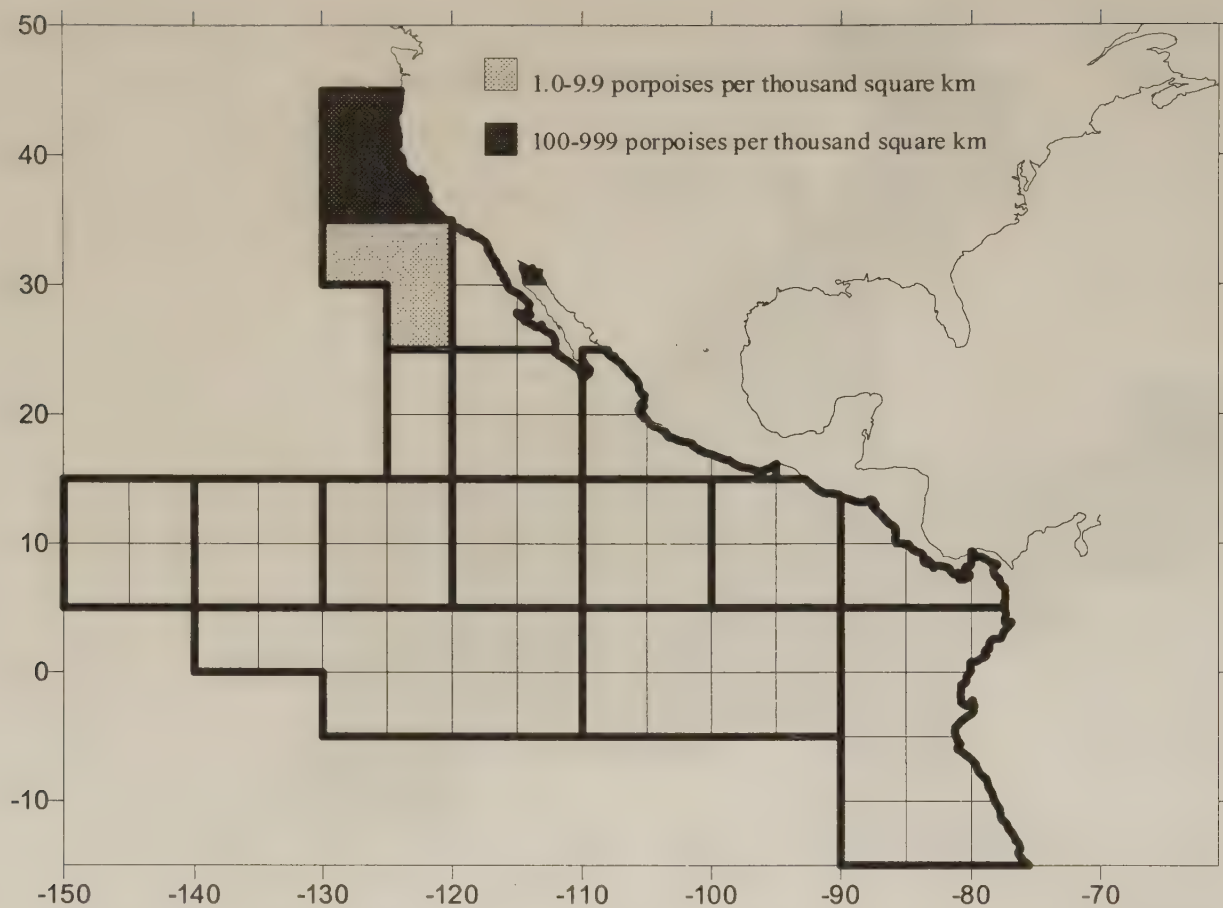


Figure 20. Dall's porpoise (*Phocoenoides dalli*) and vaquita (*Phocoena sinus*) density in the eastern Pacific Ocean. Blank squares contained no sightings.

Table 1a. Beaufort ranges, truncation distances, group size strata, and $f(0)$ and $g(0)$ values used to estimate balaenopterid density.

Species or classification	All Regions			Northern Region			Middle Region			Gulf of California			Eastern Tropical Pacific Region		
	Beaufort Range	$g(0)$	$CV(g(0))$	$f(0) (km^{-1})$	$CV(f(0))$	Truncation Distance (km)	$f(0) (km^{-1})$	$CV(f(0))$	Truncation Distance (km)	$f(0) (km^{-1})$	$CV(f(0))$	Truncation Distance (km)	$f(0) (km^{-1})$	$CV(f(0))$	Truncation Distance (km)
Balaenopteridae															
<i>Balaenoptera acutorostrata</i>	0-2	0.84	0.22 1, 2	0.362	0.197	3.7 2	0.366	0.17	3.7 3	0.369	0.154	3.7 4	0.369	0.154	3.7 4
<i>Balaenoptera edeni</i>															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.48	0.18	6.09 6	0.741	0.27	5.5 7
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.48	0.18	6.09 6	0.741	0.27	5.5 7
<i>Balaenoptera borealis</i>															
group size 1-3	0-5	0.9	0.07 1, 2				0.451	0.136	5.5 3						
group size 4+	0-5	1	0 1, 2				0.23	0.16	5.5 3						
<i>Balaenoptera borealis/edeni</i>															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.48	0.18	6.09 6	0.741	0.27	5.5 7
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.48	0.18	6.09 6	0.741	0.27	5.5 7
<i>Balaenoptera physalus</i>															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.48	0.18	6.09 6	0.385	0.19	5.5 7
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.48	0.18	6.09 6	0.385	0.19	5.5 7
<i>Balaenoptera musculus</i>															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3				0.385	0.19	5.5 7
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3				0.385	0.19	5.5 7
<i>Megaptera novaeangliae</i>															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.385	0.19	5.5 7	0.385	0.19	5.5 7
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.385	0.19	5.5 7	0.385	0.19	5.5 7
<i>Balaenoptera</i> spp.															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.48	0.18	6.09 6	0.662	0.272	5.5 8
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.48	0.18	6.09 6	0.662	0.272	5.5 8
unid. Large whale															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3	0.22	0.1	7.34 5	0.662	0.272	5.5 8
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3	0.22	0.1	7.34 5	0.662	0.272	5.5 8
unid. Whale															
group size 1-3	0-5	0.9	0.07 1, 2	0.462	0.156	5.5 2	0.451	0.136	5.5 3				0.662	0.272	5.5 8
group size 4+	0-5	1	0 1, 2	0.215	0.184	5.5 2	0.23	0.16	5.5 3				0.662	0.272	5.5 8

1. Barlow 1995

2. Barlow 1997

3. Weighted average (calculated as described in the Methods section) of values from Barlow and Gerrodette (1996) and Barlow (1997)

4. Barlow and Gerrodette 1996

5. Gerrodette and Palacios 1996. CV's and truncation distances came from Gerrodette's original output files.

6. Gerrodette and Palacios 1996. CV's and truncation distances are approximate because the original data were unavailable.

7. Wade and Gerrodette 1993

8. Weighted average (calculated as described in the Analytical Methods section) of values from Wade and Gerrodette (1993)

Table 1b. Beaufort ranges, truncation distances, group size strata, and $f(0)$ and $g(0)$ values used to estimate physeterid, ziphiid, and unidentified whale density.

Species or classification	All Regions			Northern Region			Middle Region			Gulf of California			Eastern Tropical Pacific Region		
	Beaufort Range	$g(0)$	$CV(g(0))$	reference	$f(0)$ (km ⁻¹)	$CV(f(0))$	Truncation Distance (km)	reference	$f(0)$ (km ⁻¹)	$CV(f(0))$	Truncation Distance (km)	reference	$f(0)$ (km ⁻¹)	$CV(f(0))$	Truncation Distance (km)
Physeteridae															
<i>Physeter macrocephalus</i>															
group size 1-3	0-5	0.87	0.08	9	0.462	0.156	5.55	2	0.451	0.136	5.55	3	0.25	0.077	5.84
group size 4+	0-5	0.87	0.08	9	0.215	0.184	5.55	2	0.23	0.16	5.55	3	0.25	0.077	5.84
<i>Kogia breviceps</i>	0-2	0.35	0.29	2, 9	0.855	0.169	3.7	2	1.194	0.201	5.55	3	1.105	0.15	5.5
<i>Kogia simus</i>	0-2	0.35	0.29	2, 9	0.855	0.169	3.7	2	1.194	0.201	5.55	3	1.105	0.15	5.5
<i>Kogia simus/breviceps</i>	0-2	0.35	0.29	2, 9	0.855	0.169	3.7	2	1.194	0.201	5.55	3	1.105	0.15	5.5
Ziphiidae															
<i>Berardius bairdii</i>															
group size 1-3	0-5	0.96	0.23	10	0.462	0.156	5.55	2	0.451	0.136	5.55	3	0.238	0.147	5.55
group size 4+	0-5	0.96	0.23	10	0.215	0.184	5.55	2	0.23	0.16	5.55	3	0.238	0.147	5.55
<i>Indopacetus pacificus?</i>															
group size 1-3	0-5	0.96	0.23	10									0.238	0.147	5.55
group size 4+	0-5	0.96	0.23	10									0.238	0.147	5.55
<i>Ziphius cavirostris</i>	0-2	0.23	0.35	10	0.362	0.197	3.7	2	0.366	0.17	3.7	3	0.91	0.19	3.57
<i>Mesoplodon peruvianus</i>	0-2	0.45	0.23	10					0.366	0.17	3.7	3	0.369	0.16	3.71
<i>Mesoplodon</i> spp.	0-2	0.45	0.23	10	0.362	0.197	3.7	2	0.366	0.17	3.7	3	0.369	0.16	3.71
<i>Mesoplodon densirostris</i>	0-2	0.45	0.23	10					0.366	0.17	3.7	3	0.369	0.16	3.71
<i>Mesoplodon</i> sp. A	0-2	0.45	0.23	10									0.369	0.16	3.71
ziphiid whale	0-2	0.354	0.266	11	0.362	0.197	3.7	2	0.366	0.17	3.7	3	0.369	0.16	3.71
unid. Cetacean	0-2	0.84	0.22	1, 2	0.362	0.197	3.7	2	0.366	0.17	3.7	3	0.67	0.166	4.97
unid. Small whale	0-2	0.84	0.22	1, 2	0.362	0.197	3.7	2	0.366	0.17	3.7	3	0.72	0.32	4.53

1. Barlow 1995

2. Barlow 1997

3. Weighted average (calculated as described in the Methods section) of values from Barlow and Gerrodette (1996) and Barlow (1997)

4. Barlow and Gerrodette 1996

5. Gerrodette and Palacios 1996. CV's and truncation distances came from Gerrodette's original output files.

7. Wade and Gerrodette 1993

9. Barlow and Sexton 1996

10. Barlow 1999

11. Weighted average (see Analytical Methods section for details) of values in Barlow 1999

Table 1c. Beaufort ranges, truncation distances, group size strata, and $f(0)$ and $g(0)$ values used to estimate delphinid density (part I).

Species or classification	All Regions			Northern Region			Middle Region			Gulf of California			ETP Region		
	Beaufort	$g(0)$	CV ($g(0)$)	reference	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation (km)	reference	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation (km)	reference	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation (km)
Delphinidae															
<i>Stenella attenuata</i> (offshore)									0.31	0.09	7.71	6	0.287	0.11	5.5
Northeastern spotted	0-5	1	0.1, 2										0.468	0.13	5.5
Western/southern spotted	0-5	1	0.1, 2						0.31	0.09	7.71	6	0.397	0.24	5.5
<i>Stenella attenuata graffmani</i>	0-5	1	0.1, 2						0.31	0.09	7.71	6			
<i>Stenella attenuata</i> (unid. Subsp.)															
NE, < 100 n mi from shore	0-5	1	0.1, 2										0.291	0.125	5.5
NE, > 100 n mi from shore	0-5	1	0.1, 2										0.287	0.11	5.5
W/S, < 100 n mi from shore	0-5	1	0.1, 2										0.463	0.138	5.5
W/S, > 100 n mi from shore	0-5	1	0.1, 2						0.28	0.09	7.71	6	0.468	0.13	5.5
<i>Stenella longirostris orientalis</i>	0-5	1	0.1, 2										0.387	0.17	5.5
<i>Stenella longirostris</i> hybrid	0-5	1	0.1, 2										0.541	0.13	5.5
<i>Stenella longirostris centroamericana</i>	0-5	1	0.1, 2										0.387	0.17	5.5
<i>Stenella longirostris</i> (unid. Subsp.)	0-5	1	0.1, 2										0.448	0.151	5.5
<i>Delphinus capensis</i> (long-beak)															
group size 1-20	0-5	0.77	0.14 1, 2		1.567	0.348	3.7	2	1.667	0.289	3.7	3	0.447	0.37	5.5
group size 21-100	0-5	1	0.1, 2		0.519	0.186	3.7	2	0.783	0.24	3.7	3	0.447	0.37	5.5
group size 100+	0-5	1	0.1, 2		0.503	0.193	3.7	2	0.518	0.222	3.7	3	0.447	0.37	5.5
<i>Delphinus delphis</i> (short-beak)															
group size 1-20	0-5	0.77	0.14 1, 2		1.567	0.348	3.7	2	1.667	0.289	3.7	3			
group size 21-100	0-5	1	0.1, 2		0.519	0.186	3.7	2	0.783	0.24	3.7	3			
group size 100+	0-5	1	0.1, 2		0.503	0.193	3.7	2	0.518	0.222	3.7	3			
Northern common dolphin (ETP only)	0-5	1	0.1, 2										0.447	0.37	5.5
Central common dolphin (ETP only)	0-5	1	0.1, 2										0.351	0.36	5.5
Southern common dolphin (ETP only)	0-5	1	0.1, 2										0.669	0.21	5.5
<i>Delphinus delphis</i> (unid. Subsp.)															
group size 1-20	0-5	0.77	0.14 1, 2		1.567	0.348	3.7	2	1.667	0.289	3.7	3			
group size 21-100	0-5	1	0.1, 2		0.519	0.186	3.7	2	0.783	0.24	3.7	3			
group size 100+	0-5	1	0.1, 2		0.503	0.193	3.7	2	0.518	0.222	3.7	3			
within northern stock boundaries	0-5	1	0.1, 2										0.447	0.37	5.5
within central stock boundaries	0-5	1	0.1, 2										0.351	0.36	5.5
within southern stock boundaries	0-5	1	0.1, 2										0.669	0.21	5.5

1. Barlow 1995

2. Barlow 1997

3. Weighted average (calculated as described in the Methods section) of values from Barlow and Gerrodette (1996) and Barlow (1997)

5. Gerrodette and Palacios 1996. CV's and truncation distances came from Gerrodette's original output files.

6. Gerrodette and Palacios 1996. CV's and truncation distances are approximate because the original data were unavailable.

7. Wade and Gerrodette 1993

8. Weighted average (calculated as described in the Analytical Methods section) of values from Wade and Gerrodette 1993)

12. Weighted average (refer to Analytical Methods section for details) of values in Gerrodette and Palacios 1996

Table 1d. Beaufort ranges, truncation distances, group size strata, and $f(0)$ and $g(0)$ values used to estimate delphinid density (part II).

Species or classification	All Regions			Northern Region			Middle Region			Gulf of California			ETP Region		
	Beaufort	$g(0)$	CV ($g(0)$)	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation Dist. (km)	reference	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation Dist. (km)	reference	$f(0)$ (km^{-1})	CV ($f(0)$)	Truncation Dist. (km)	reference
<i>Stenella coeruleoalba</i>															
group size 1-20	0-5	0.77	0.14	1, 2	1.567	0.348	3.7 2	1.667	0.289	3.7 3		0.588	0.09	5.5 7	7
group size 21-100	0-5	1	0.1, 2	0.519	0.186	3.7 2	0.783	0.24	3.7 3			0.588	0.09	5.5 7	7
group size 100+	0-5	1	0.1, 2	0.503	0.193	3.7 2	0.518	0.222	3.7 3			0.588	0.09	5.5 7	7
<i>Steno bredanensis</i>												1.69	0.255	3.89 5	5
<i>Tursiops truncatus</i>															
group size 1-20	0-5	0.74	0.39	1, 2				0.661	0.405	3.7 3		0.519	0.22	5.5 7	7
group size 20+	0-5	1	0.1, 2					0.373	0.199	3.7 3		0.519	0.22	5.5 7	7
<i>Grampus griseus</i>															
group size 1-20	0-5	0.74	0.39	1, 2	0.366	0.167	3.7 2	0.661	0.405	3.7 3		1.31	0.21	3.52 5	5
group size 20+	0-5	1	0.1, 2	0.366	0.167	3.7 2	0.373	0.199	3.7 3			1.31	0.21	3.52 5	5
<i>Lagenorhynchus obliquidens</i>															
group size 1-20	0-5	0.77	0.14	1, 2	1.567	0.348	3.7 2	1.667	0.289	3.7 3		1.724	0.255	3.7 4	4
group size 21-100	0-5	1	0.1, 2	0.519	0.186	3.7 2	0.783	0.24	3.7 3			0.905	0.24	3.7 4	4
group size 100+	0-5	1	0.1, 2	0.503	0.193	3.7 2	0.518	0.222	3.7 3			0.528	0.239	3.7 4	4
<i>Lagenodelphis hosei</i>												0.33	0.32	5.5 7	7
<i>Lissodelphis borealis</i>															
group size 1-20	0-5	0.77	0.14	1, 2	1.567	0.348	3.7 2	1.667	0.289	3.7 3					
group size 21-100	0-5	1	0.1, 2	0.519	0.186	3.7 2	0.783	0.24	3.7 3						
group size 100+	0-5	1	0.1, 2	0.503	0.193	3.7 2	0.518	0.222	3.7 3						
<i>Peponocephala electra</i>															
<i>Feresa attenuata</i>	0-5	1	0.1, 2									0.242	0.36	5.5 7	7
<i>Pseudorca crassidens</i>	0-5	1	0.1, 2									0.707	0.2	5.5 7	7
<i>Orcinus orca</i>												1.163	0.75	5.5 7	7
group size 1-20	0-5	0.74	0.39	1, 2	0.366	0.167	3.7 2	0.661	0.405	3.7 3		0.379	0.31	5.5 7	7
group size 20+	0-5	1	0.1, 2	0.366	0.167	3.7 2	0.373	0.199	3.7 3			0.379	0.31	5.5 7	7
<i>Globicephala</i> spp.															
group size 1-20	0-5	0.74	0.39	1, 2	0.366	0.167	3.7 2	0.661	0.405	3.7 3		0.541	0.13	5.5 7	7
<i>Globicephala macrorhynchus</i>												0.541	0.13	5.5 7	7
group size 1-20	0-5	0.74	0.39	1, 2	0.366	0.167	3.7 2	0.661	0.405	3.7 3		0.63	0.32	4.53 6	6
group size 20+	0-5	1	0.1, 2	0.366	0.167	3.7 2	0.373	0.199	3.7 3			0.63	0.32	4.53 6	6
unid. Dolphin															
group size 1-20	0-5	0.77	0.14	1, 2	1.567	0.348	3.7 2	1.667	0.289	3.7 3		0.4	0.091	7.71 5	5
group size 21-100	0-5	1	0.1, 2	0.519	0.186	3.7 2	0.783	0.24	3.7 3			0.4	0.091	7.71 5	5
group size 100+	0-5	1	0.1, 2	0.503	0.193	3.7 2	0.518	0.222	3.7 3			0.4	0.091	7.71 5	5

1. Barlow 1995

2. Barlow 1997

3. Weighted average (calculated as described in the Methods section) of values from Barlow and Gerrodette (1996) and Barlow (1997)

4. Barlow and Gerrodette 1996

5. Gerrodette and Palacios 1996. CV's and truncation distances came from Gerrodette's original output files.

6. Gerrodette and Palacios 1996. CV's and truncation distances are approximate because the original data were unavailable.

7. Wade and Gerrodette 1993

Table 1e. Beaufort ranges, truncation distances, group size strata, and $f(0)$ and $g(0)$ values used to estimate phocoenid density.

Species or classification	All Regions				Northern Region				Middle Region			
	Beaufort	$g(0)$	CV($g(0)$)	reference	$f(0)$ (km^{-1})	CV($f(0)$)	Truncation Distance (km)	reference	$f(0)$ (km^{-1})	CV($f(0)$)	Truncation Distance (km)	reference
Phocoenidae												
<i>Phocoena sinus</i> *												
<i>Phocoenoides dalli</i>	0-2	0.79	0.1	1, 2	0.855	0.169	3.7	2	1.194	0.201	3.7	3

1. Barlow 1995

2. Barlow 1997

3. Weighted average (calculated as described in the Methods section) of values from Barlow and Gerrodette (1996) and Barlow (1997)

* Density and abundance estimates for the vaquita are from Jaramillo-Legorreta *et al.* 1999.

Table 2. Estimated density (# individuals per 1000 km²), abundance, and CV of minke whales (*Balaenoptera acutorostrata*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
A	0.4	258	0.44
B	0.3	252	0.71
C	0.2	79	1.00

Table 3. Estimated density (# individuals per 1000 km²), abundance, and CV of sei or Bryde's whales (*Balaenoptera borealis* or *edeni*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV	geographic stratum	estimated density	estimated abundance	CV
47	0.1	53	0.75	160	1.9	593	0.41
48	0.1	53	0.75	161	2.0	613	0.41
59	0.1	16	0.71	162	0.8	239	0.53
85	4.0	849	0.58	163	1.3	406	0.58
86	0.5	121	0.60	164	0.8	261	0.60
87	0.3	88	1.00	165	0.4	116	0.65
101	0.1	33	1.00	166	1.9	582	0.53
102	0.1	33	1.00	167	1.4	428	0.53
103	0.2	45	1.00	168	1.0	960	0.78
104	0.8	247	0.49	169	1.0	960	0.78
105	0.9	254	0.56	170	1.0	960	0.78
106	0.3	85	1.00	179	1.8	191	0.53
119	0.1	24	1.00	180	1.8	191	0.53
120	0.5	139	0.71	181	1.8	191	0.53
121	0.4	118	0.76	201	0.1	43	1.00
123	1.8	542	0.67	202	3.1	962	0.72
125	1.1	336	0.58	203	1.4	422	0.55
127	0.5	164	0.71	204	1.6	503	0.57
137	0.4	37	0.71	205	0.2	51	1.00
138	0.3	60	1.00	206	0.9	274	0.86
139	0.2	47	1.00	208	0.3	105	1.00
140	0.1	24	1.00	211	0.3	87	1.00
141	0.4	122	0.61	212	0.5	164	0.81
143	0.1	39	1.00	214	1.3	404	0.58
147	1.0	320	0.84	215	4.3	2661	0.66
148	0.9	268	0.71	216	4.3	2661	0.66
159	0.4	114	0.58				

Table 4. Estimated density (# individuals per 1000 km²), abundance, and CV of fin whales (*Balaenoptera physalus*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
22	0.3	70	0.71
23	0.3	70	0.71
34	0.4	14	1.00
35	0.4	193	0.52
36	0.4	193	0.52
46	4.8	600	0.28
47	1.0	501	0.42
48	1.0	501	0.42
58	0.5	69	0.58
59	1.8	451	0.35
179	5.4	567	0.89
180	5.4	567	0.89
181	5.4	567	0.89
182	10.3	279	0.53

Table 5. Estimated density (# individuals per 1000 km²), abundance, and CV of blue whales (*Balaenoptera musculus*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
35	0.2	87	0.52
36	0.2	87	0.52
46	3.5	442	0.28
47	0.5	234	0.42
48	0.5	234	0.42
58	5.0	673	0.45
59	3.5	887	0.21
60	0.6	153	0.71
72	0.2	55	0.58
86	1.4	378	0.45
87	0.3	80	0.71
104	0.1	28	0.71
119	0.4	110	0.46
120	0.3	96	0.59
139	0.1	24	0.71
140	0.5	162	0.43
141	0.2	49	1.00
163	0.2	54	1.00
200	0.1	33	1.00
202	0.6	170	0.58
203	0.7	219	0.71
204	0.1	31	1.00
205	0.2	53	1.00
213	0.1	30	1.00

Table 6. Estimated density (# individuals per 1000 km²), abundance, and CV of humpback whales (*Megaptera novaeangliae*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
34	4.3	166	0.37
46	6.9	869	0.26
47	0.1	47	1.00
48	0.1	47	1.00
59	0.4	92	0.44
71	1.1	73	0.71
137	0.2	19	0.71
158	4.4	457	0.50
179	0.3	29	0.71
180	0.3	29	0.71
181	0.3	29	0.71
200	0.9	239	0.58
203	0.2	63	1.00

Table 7. Estimated density (# individuals per 1000 km²), abundance, and CV of sperm whales (*Physeter macrocephalus*) in the eastern Pacific Ocean based on 1986-1996 summer/ fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV	geographic stratum	estimated density	estimated abundance	CV
22	1.7	419	0.71	147	0.6	194	1.00
23	1.7	419	0.71	148	1.0	306	0.71
35	0.2	75	0.71 ^a	149	0.7	204	1.00
36	0.2	75	0.71	150	0.1	50	1.00
46	3.5	440	0.59	151	0.1	50	1.00
47	1.0	507	0.47	158	9.8	1010	0.86
48	1.0	507	0.47	159	5.1	1583	0.41
58	0.3	35	0.71	160	3.5	1072	0.50
59	1.1	282	0.42	161	0.5	158	0.58
60	0.2	64	1.00	162	0.9	271	0.58
71	0.8	53	0.71	164	0.5	169	1.00
72	0.5	128	0.43	165	0.5	164	0.71
73	0.2	63	1.00	166	0.5	140	1.00
85	1.0	206	0.71	179	2.3	240	0.55
86	1.3	348	0.53	180	2.3	240	0.55
87	0.4	110	1.00	181	2.3	240	0.55
103	3.0	886	0.72	200	10.5	2829	0.69
104	0.1	31	0.71	201	1.0	318	0.64
105	0.3	78	1.00	202	1.0	295	0.60
106	0.7	195	0.71	203	0.5	162	1.00
111	0.1	56	1.00	204	1.0	312	1.00
112	0.1	56	1.00	205	0.8	253	0.58
119	1.8	487	0.47	206	3.3	1004	0.66
121	0.4	113	0.71	207	0.1	36	1.00
124	0.9	261	0.77	211	7.1	2057	0.67
137	4.3	450	0.43	212	0.2	63	1.00
138	2.6	534	0.62	213	0.2	66	1.00
139	4.1	1253	0.52	214	0.3	77	1.00
140	1.0	297	0.75	215	0.7	409	0.58
141	1.1	336	0.71	216	0.7	409	0.58
142	1.2	378	1.00	218	15.2	11969	0.71
143	0.9	272	0.64	219	15.2	11969	0.71
144	1.0	311	0.58	220	15.2	11969	0.71
145	2.3	702	1.00				

Table 8. Estimated density (# individuals per 1000 km²), abundance, and CV of dwarf (*Kogia sima*) and pygmy (*Kogia breviceps*) sperm whales in the eastern Pacific Ocean based on 1986-1996 summer/ fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
A	2.0	1252	0.63
B	6.3	4956	1.71
C	12.1	5690	0.72
D	2.5	1439	1.00
E	6.3	7137	0.58
F	20.0	15035	0.46
H	5.2	6298	1.00
I	19.4	23656	0.58
J	9.0	10992	0.71
K	27.5	33437	0.48
L	17.6	20901	0.49
M	26.9	20421	0.52
P	4.0	10061	0.80
Southern Gulf of California	50.1	5278	0.62

Table 9. Estimated density (# individuals per 1000 km²), abundance, and CV of Cuvier's beaked whales (*Ziphius cavirostris*) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
A	3.1	1991	0.54
B	5.4	4299	0.55
E	0.3	365	1.00
F	2.5	1906	0.62
G	5.4	6540	0.58
J	2.2	2624	0.71
K	3.0	3638	0.82
L	3.5	4142	0.52
M	3.7	2816	0.60
N	13.0	40306	1.00
O	7.3	18094	0.71
Southern Gulf of California	38.0	4004	0.73

Table 10. Estimated density (# individuals per 1000 km²), abundance, and CV of Baird's beaked whales (*Berardius bairdii*) and tropical bottlenose whales (*Indopacetus pacificus*?) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
35	0.5	239	0.5
36	0.5	239	0.5
46	1.0	128	0.7
47	0.3	161	1.0
48	0.3	161	1.0
59	0.2	60	1.0
71	1.2	79	1.0
72	0.1	37	1.0
144	0.4	114	1.0
160	0.2	58	1.0
161	0.4	119	1.0

Table 11. Estimated density (# individuals per 1000 km²), abundance, and CV of small beaked whales (*Mesoplodon* spp.) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys. For strata in which there was only one sighting, CV=1.0 is a minimum estimate of variance, assuming that the sightings follow a Poisson distribution.

geographic stratum	estimated density	estimated abundance	CV
A	1.0	647	0.62
E	1.0	1120	0.76
F	3.7	2765	0.37
I	1.6	1924	1.00
J	1.7	2012	0.68
K	3.4	4082	0.48
L	1.1	1263	0.50
M	1.5	1140	0.65
O	1.9	4624	1.00
P	5.0	12429	0.43
Southern Gulf of California	6.4	672	1.00

Table 12. Estimated density (# individuals per 1000 km²), abundance, and CV of dolphins (family Delphinidae) in the eastern Pacific Ocean based on 1986-1996 summer/fall research vessel surveys.

geographic stratum	estimated density	estimated abundance	CV	geographic stratum	estimated density	estimated abundance	CV
22	71.6	17697	0.45	143	525.4	161092	1.42
23	71.6	17697	0.45	144	303.1	92952	0.45
34	81.8	3172	0.48	145	184.2	56468	0.31
35	157.2	71619	0.43	146	296.5	90905	0.26
36	157.2	71619	0.43	147	276.6	84798	0.36
46	712.5	89802	0.32	148	456.2	139895	0.40
47	607.1	297737	0.26	149	154.2	47291	0.61
48	607.1	297737	0.26	150	281.1	172391	0.47
58	1617.3	215974	0.25	151	281.1	172391	0.47
59	549.4	140808	0.22	158	334.9	34667	0.27
60	143.7	37460	0.36	159	218.1	67254	0.15
71	1645.6	112490	0.62	160	269.7	83326	0.22
72	191.7	51458	0.36	161	526.9	162811	0.75
73	157.3	43135	0.36	162	444.6	137361	0.20
85	1093.3	231217	0.18	163	833.0	257377	0.25
86	798.0	208341	0.45	164	356.0	109995	0.30
87	309.3	88364	0.26	165	325.4	100534	0.22
88	143.0	40854	0.34	166	111.1	34315	0.23
101	761.9	187483	0.21	167	544.7	168309	0.36
102	761.9	187483	0.21	168	216.1	200276	0.39
103	484.0	142751	0.17	169	216.1	200276	0.39
104	218.9	64559	0.17	170	216.1	200276	0.39
105	153.4	45246	0.28	179	1627.9	171610	0.27
106	295.1	87014	0.41	180	1627.9	171610	0.27
111	10.5	6163	0.61	181	1627.9	171610	0.27
112	10.5	6163	0.61	182	338.5	9225	0.59
118	827.8	116841	0.41	200	1706.6	460530	0.34
119	1258.7	344030	0.26	201	1614.7	498909	0.32
120	721.6	217853	0.18	202	2342.5	723787	0.42
121	780.6	235682	0.16	203	1015.9	313909	0.58
122	417.2	125972	0.25	204	663.3	204962	0.30
123	468.5	141438	0.22	205	505.7	105692	0.21
124	400.2	120820	0.45	206	266.4	55671	0.28
125	112.5	33957	0.34	207	585.8	181005	0.35
126	512.4	154715	0.35	208	492.0	152007	0.27
127	456.2	137729	0.29	209	466.1	144020	0.31
128	148.8	89857	0.31	211	443.0	128410	0.48
129	148.8	89857	0.31	212	751.6	230462	0.30
130	335.3	202493	0.57	213	421.5	129247	0.42
131	335.3	202493	0.57	214	240.0	73589	0.49
137	391.8	40938	0.27	215	192.4	117980	0.30
138	604.5	125987	0.38	216	192.4	117980	0.30
139	553.4	169609	0.26	218	485.8	382858	0.67
140	1003.4	307661	0.27	219	485.8	382858	0.67
141	670.9	205717	0.18	220	485.8	382858	0.67
142	411.5	126175	0.25				

Table 13. Estimated density (# individuals per 1000 km²), abundance, and CV of Dall's porpoise (*Phocoenoides dalli*) and vaquita* (*Phocoena sinus*) in the eastern Pacific Ocean.

geographic stratum	estimated density	estimated abundance	CV
182	142.0	567	0.51
A	115.8	73877	0.36
B	3.6	2843	0.58

*Vaquita estimates are from Jaramillo-Legorreta *et al.* 1999

